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2017 Coastal Master Plan

Attachment C3-24: Integrated Compartment Model Uncertainty Analysis

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Coastal Protection and Restoration Authority

This document was prepared in support of the 2017 Coastal Master Plan being prepared by the Coastal Protection and Restoration Authority (CPRA). CPRA was established by the Louisiana Legislature in response to Hurricanes Katrina and Rita through Act 8 of the First Extraordinary Session of 2005. Act 8 of the First Extraordinary Session of 2005 expanded the membership, duties, and responsibilities of CPRA and charged the new authority to develop and implement a comprehensive coastal protection plan, consisting of a master plan (revised every five years) and annual plans. CPRA's mandate is to develop, implement, and enforce a comprehensive coastal protection and restoration master plan.

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Executive Summary

In long-term coastal planning efforts, especially one as critical as Louisiana's coastal master plan, it is important to consider the effects of uncertainties on predicted outcomes. To build upon the 2012 Coastal Master Plan modeling effort, the approach described herein provides a framework to perform the uncertainty analysis (UA).

A coast wide Integrated Compartment Model (ICM) has been developed as a landscape model for use in the 2017 Coastal Master Plan. It includes hydrology, water quality, morphology, vegetation, barrier islands, and habitat suitability indices. In the modeling effort of the 2017 Coastal Master Plan, two primary sources of uncertainties were investigated. First is the uncertainty in the environmental drivers, namely, eustatic sea level rise, subsidence, precipitation, and evapotranspiration. This uncertainty was addressed through an environmental scenario approach, where the modeled landscape response was evaluated across different combinations of values for these environmental drivers (Appendix C: Chapter 2). The second source of uncertainty investigated is associated with the calculations of critical model variables and how they influence key model output. This component of the UA is the focus of this report. The main objective of this analysis is to quantify the magnitude of the uncertainty in key model output driven by uncertainties in critical model variables. Land area was identified as the key model output for the analysis. The analysis performed here is applied to the validated Future Without Action (FWOA) ICM model simulation, also referred to here as the base case.

The uncertainty analysis approach utilized in this report was based on applying perturbations to model variables that are directly linked to the calculations of land area. The model variables examined include water level, salinity, wetland types, suspended mineral sediment concentration, and organic accretion. The magnitudes of the perturbations were estimated based on the calibration errors and were then applied annually and for the duration of the 50-year simulations.

The perturbations were initially applied individually to identify which model variables had significant impacts on land area. The individual perturbations showed that water level and organic accretion have the most influence on land area. Salinity, while having an influence on the wetland type, did not have significant impact on land area. Land area was also not impacted significantly by total suspended sediment. Perturbations to predicted areas of different wetland types were not included here as they were controlled by the prevailing hydrologic conditions. As such, the uncertainty in land area, as determined by wetland type, was determined indirectly via perturbations to hydrologic conditions, and as such, uncertainties due to vegetation type were removed from further consideration.

The uncertainty range resulting from linearly adding the uncertainty of the individual perturbations was compared to the outcome of a set of 16 permutations designed to examine the interdependency among the uncertainty of the model variables. The comparison showed that the uncertainty range resulting from the 16 permutation composite set was wider than the linearly added uncertainty bracket. This outcome demonstrates that interdependency among the model variables is important. The results of the composite experiments show that water level, organic accretion, and their interdependence are the most influential on coast wide land area. The 16 permutations of composite perturbations were performed for the high scenario FWOA for both ICM_v1 and ICM_v3, which were model settings used for individual project-level analyses and alternative/plan-level analyses conducted for the 2017 Coastal Master Plan, respectively. The 16 uncertainty permutations were also performed on the Draft 2017 Coastal Master Plan under the high scenario. In general, model prediction uncertainty decreased over time under

the high scenario FWOA due to relative sea level rise rates which overwhelmed the uncertainty introduced by the perturbed model output variables. Regardless of the perturbations performed for each permutation, the coast wide land area asymptotically approached the same lower limit in all permutations over time. With the Draft 2017 Coastal Master Plan implemented, the land area no longer approached this lower limit under the high scenario. This resulted in more uncertainty due to the presence of more land being present within the model domain in later decades. Spatial analysis of the model uncertainty presented here shows that the most uncertain areas within the model fall outside of the project footprint areas. This indicates a reasonable level of confidence in the primary land change numbers predicted by ICM during the 2017 Coastal Master Plan analysis.

Throughout all of the uncertainty analysis runs conducted, the total range of land area was 9,400 km^2 to 14,000 km^2, with a baseline prediction of 11,700 km^2 under the low scenario FWOA using ICM_v1. Under the high scenario, using ICM_v1, the land area ranged from 4,000 km^2 to 8,200 km^2, with a baseline prediction of 5,300 km^2. Under the high scenario, using ICM_v3, the land area ranged from 4,000 km^2 to 8,700 km^2, with a baseline prediction of 5,600 km^2. Finally, under the high scenario using ICM_v3, the Draft 2017 Coastal Master Plan land area ranged from 6,800 km^2 to 11,300 km^2, with a baseline prediction of 8,600 km^2.

Many model input parameters were not able to be perturbed by the methodology followed for the uncertainty analysis, in which model performance errors were used to assign a perturbation factor to model outputs. The modeling team determined that the ICM prediction of land area at year 50 seemed to be particularly sensitive to three such parameters: subsidence rates, organic matter accretion, and marsh collapse threshold values. The spatial extent of model-predicted land area changed substantially due to setting these variables at extreme values. Of the marsh collapse threshold values, the year 50 prediction of land area within the model domain was most sensitive to the saline marsh inundation-induced collapse threshold; a finding in agreement with the fact that the majority of land remaining at year 50 under the medium scenario is saline marsh. The extent of land impacted by the total range tested in subsidence rates and organic matter input rates were roughly the same magnitude as the saline marsh collapse threshold. The land area predicted at year 50 was not as sensitive to collapse thresholds for brackish, intermediate, or fresh marsh types.

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List of Abbreviations

BD	Bulk Density
CPRA	Coastal Protection and Restoration Authority
G001	Model group 1 representing the Future Without Action from ICM_v1
G300	Model group 300 representing the Future Without Action from ICM_v3
G400	Model group 400 representing the Draft Master Plan from ICM_v3
FWOA	Future Without Action
ICM	Integrated Compartment Model
ICM_v1	Version 1 of the ICM
ICM_v3	Version 3 of the ICM
MAE	Mean Absolute Error
OM	Organic Matter
RMSE	Root Mean Square Error
S01	Low Future Environmental Scenario
S03	High Future Environmental Scenario
S04	Medium Future Environmental Scenario
TSS	Total Suspended Solids
UA	Uncertainty Analysis

1.0 Introduction

1.1 Rationale and Background

Understanding and quantifying uncertainties associated with numerical model predictions is important for planning activities such as Louisiana's coastal master plan. An uncertainty analysis (UA) was conducted for the 2012 Coastal Master Plan landscape modeling effort (Habib & Reed, 2013), but the results were not available in time to be used in the decision making (plan formulation) process. A new landscape modeling approach was developed for use in the 2017 Coastal Master Plan. The Integrated Compartment Model (ICM) is a coast wide landscape model capable of generating 50-year simulations. It is comprised of the following subroutines: hydrology and water quality, morphology, vegetation, barrier islands, and habitat suitability indices. An overview of the ICM components is found in Appendix C: Chapter 3.

Two primary sources of uncertainties were investigated for the ICM. First, is the uncertainty in the environmental drivers that govern the overall model dynamics. This was addressed through identifying plausible values for environmental drivers that are combined into a number of scenarios that then allow examination of the landscape response to variations in the drivers (Appendix C: Chapter 2). The environmental drivers evaluated include eustatic sea level rise, subsidence, precipitation, and evapotranspiration. The second source of uncertainty is associated with the values of variables calculated by the numerical models. This component of the UA is the focus of this report. A goal of this analysis is to understand the magnitude of the uncertainty in the output of the ICM due to uncertainties in specific model variables. The basic structure of the ICM is described in Appendix C: Chapter 3. As information is passed from one ICM subroutine to another (e.g., from the hydrology subroutine to the morphology subroutine), the effects of uncertainties on model outputs may increase. Conversely, uncertainties could be dampened or reduced due to temporal or spatial integration calculations (e.g., use of two-week mean salinity in the morphology subroutine based on daily outputs from the hydrology subroutine). The dual sources of uncertainty (environmental scenarios versus model parameters) are assumed independent of one another; however, the relative sensitivity of the ICM to these two sources is not. For example, as relative sea level rises substantially in later decades under a high scenario, the model prediction of land area will likely be much more sensitive to sea level rise rates than a temporally static model error in mean water level predictions; the uncertainty due to model error is inversely proportional to environmental scenario "severity". Therefore, the low scenario for future environmental conditions (e.g., low sea level rise, low rates of subsidence, and a relatively wet future) was chosen for the first phase of this analysis of model parameter uncertainties. In other words, the first phase of this analysis assumed that the uncertainty in land area with respect to model error will be greatest under a least "severe" future environment.

A second phase of analysis was conducted, in which uncertainty in land area prediction was analyzed under the high scenario for future environmental conditions (e.g., high rates of relative sea level rise) (Appendix C: Chapter 2). This second phase focused on the uncertainty in land prediction for three specific simulations: the high scenario Future Without Action (FWOA) using version 1 of the ICM (ICM_v1) [G001], the high scenario FWOA using version 3 of the ICM (ICM_v3 [G300]), and the high scenario Future With Draft Master Plan using ICM_v3 [G400]. The first of these three simulations was chosen because it is identical in configuration to the model version used to analyze individual restoration project performance within the CPRA Planning Tool (Appendix D: Planning Tool). The second and third simulations of the second phase were chosen since they are the model configuration used to quantify the performance of the master plan under the high scenario, as formulated by CPRA.

In addition to model parameters assessed via an uncertainty analysis, a final phase of this analysis focused on assessing the relative sensitivity of land area predictions at year 50 to ranges in model input parameters that were difficult to quantitatively assess with respect to model error: subsidence rates, organic matter accretion, and marsh collapse threshold values. The spatial extent of model-predicted land area may vary greatly depending on which value for such parameters was initially chosen. A sensitivity analysis was conducted to analyze model responses to acceptable ranges of these three parameters.

1.2 Terminology

Below is a brief definition of five terms that are used in this document. The definitions provided here are to ensure clarity of what each term refers to herein:

- Parameters: This term refers to model coefficients such as roughness, diffusion, bulk density, etc.
- Variables: This term refers to "state variables" such as water level, salinity, and anything the model actually "calculates."
- Drivers: This term refers to external boundary conditions that "drive" the model (e.g., eustatic sea level rise, subsidence, precipitation, evapotranspiration, etc.).
- Perturbations: This term refers to the adjustments made to each model output variable before the variable was passed on to other model subroutines. The adjustments made were based upon model and input data error/variability as described in Section 0.
- Permutations: This term refers to the unique combinations of perturbed model variables when more than one variable was perturbed at the same time during the experiments analyzing composite uncertainties. This is discussed in Section 4.5.

2.0 Approach

2.1 Overview of 2012 Coastal Master Plan Uncertainty Analysis

The 2012 Coastal Master Plan effort included an UA (Habib & Reed, 2013). The 2012 UA focused on parametric-related uncertainties, which are due to imperfect knowledge about the parameters and relationships used within the models. Due to the large number of individual models used in the 2012 Coastal Master Plan, a practical approach was followed where a reduced set of model parameters (34) was identified as being most uncertain. A stratified sampling experiment was designed from pre-defined simple probability distributions of the selected parameters. Two phases of the UA were conducted. The first phase (project-level) focused on examining the impacts of parameter uncertainties on model predictions and comparing such uncertainties to the predicted impacts of individual projects. The second phase (alternative-level) focused on comparing model uncertainties in predicting the future without action conditions versus a draft version of the 2012 master plan.

Questions asked in the 2012 UA:

- How uncertain are the models in predicting changes in key ecosystem metrics?
- Does the uncertainty vary spatially across the coast and temporally into future years?
- How do parameter-induced uncertainties compare with those due to other large-scale environmental (external) drivers? The 2012 effort included a comparison of land-area

predictions with two FWOA environmental scenarios (moderate and less optimistic), which reflected uncertainties due to large-scale external drivers such as subsidence, eustatic sea level rise, precipitation, etc.
- How can the uncertainty analysis inform decisions?

Lessons learned from the 2012 UA:

- The model-induced uncertainties did not greatly affect the total coast wide predicted land gains provided by the master plan over the next 50 years, although uncertainties of model predictions did grow as the predictions extended into the future years. The degree and significance of such growth varied from one region to another.
- Projected changes in ecosystem outcomes, such as oyster and brown shrimp habitat suitability indices, included greater levels of uncertainties when compared to land area. In general, model uncertainty in predicting these types of outcomes varied substantially across the coast.
- A comparable magnitude was found of the two types of uncertainties (external and parameter-related), which indicates the importance of both types in determining coast wide outcomes as well as regional patterns.

2.2 Uncertainty Analysis Approach for the Integrated Compartment Model

The ICM includes a number of subroutines (e.g., hydrology, vegetation, and barrier Islands) that have been independently calibrated. Specific model variables calculated in one subroutine are then passed to other subroutines to perform other calculations. For example, salinity is calculated in the hydrology subroutine then passed to the vegetation subroutine where it is used to determine the establishment of various vegetation species. Ultimately, output from these calculations was used to inform the development of the 2017 Coastal Master Plan.

The UA process starts with identifying key model variables during the ICM calibration process (Attachment C3-23: ICM Calibration, Validation and Performance Assessment) as those that influence important model output. The uncertainty range for these key model variables is calculated using statistical tools to assess the model performance during the calibration process. The statistical tools include Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE). In the UA, a set of numerical experiments was designed to explore how uncertainties in the model variables, calculated during calibration, influence specific model output variables. This approach was recommended by the Predictive Models Technical Advisory Committee (Attachment C5-1).

Although the ICM produces a large number of outputs that are used in plan formulation for the 2017 Coastal Master Plan, this analysis focuses on land area, as it is a key decision driver in selecting projects for inclusion within the plan. Thus, the focus of this UA is on how the uncertainties identified during calibration collectively influence the calculation of land area.

Land area is both a key decision driver during plan formulation and an important metric in reporting the master plan's effects over 50 years. In addition, different projects interact in the landscape in a complex manner to influence the amount of land maintained, created, or lost. Accordingly, such analysis can be conducted in phases collectively addressing two questions:

1. How does parametric uncertainty influence model predictions of land area (both spatial distribution as well as temporal evolution) for FWOA?
2. What is the level of confidence in the predictions of land area produced by the draft/final master plan?

The design of each phase builds on what has been learned regarding the role of parametric uncertainty in previous phases. The methodology and experimental design for this analysis were developed by primarily focusing on the first phase (addressing question 1 above). The outcome of the first phase was then used to develop a second phase of analyses which examined uncertainty in land prediction under a different environmental scenario as well as under a Future With Draft Master Plan to assess how uncertainty in land area prediction may change when implementing large-scale restoration projects.

The UA is guided by the calibration analysis for each of the subroutines that substantially influence the calculation of land area. Given that the barrier island calibration has been based on a visual fit of island profiles and shoreline position, and thus has not produced a quantified calibration error, the effect of barrier islands on total land area is not considered herein.

The following key model variables influence land area and have quantified calibration error:

- **Annual water level**: Provided by the hydrology subroutine to the morphology subroutine and used in marsh collapse threshold calculation for non-fresh vegetation wetland types.
- **Standard deviation of annual water level**: Provided by the hydrology subroutine to the vegetation subroutine and used to determine vegetation species distribution and thus vegetation wetland type.
- **Two-week salinity**: Provided by the hydrology subroutine to the morphology subroutine and used in marsh collapse threshold for fresh vegetation wetland type.
- **Annual mean salinity**: Provided by the hydrology subroutine to the vegetation subroutine and used to determine vegetation species distribution and thus vegetation wetland type.
- **Total suspended solids (TSS):** Used to calculate mineral sediment depositional rates in the hydrology subroutine, which are then used in the morphology subroutine to calculate accretion.
- **Wetland type – fresh marsh**: Wetland type provided by the vegetation subroutine to the morphology subroutine where it is used to apply marsh collapse threshold and to determine organic components of accretion.
- **Wetland type – intermediate marsh:** Wetland type provided by the vegetation subroutine to the morphology subroutine where it is used to apply marsh collapse threshold and to determine organic components of accretion.
- **Wetland type – brackish marsh**: Wetland type provided by the vegetation subroutine to the morphology subroutine where it is used to apply marsh collapse threshold and to determine organic components of accretion.
- **Wetland type – saline marsh:** Wetland type provided by the vegetation subroutine to the morphology subroutine where it is used to apply marsh collapse threshold and to determine organic components of accretion.

- **Organic loading component of annual accretion:** Calculated within the morphology subroutine based on wetland type and used to determine elevation and thus land loss/maintenance.

For the first five variables listed above, a calibration error was determined based on the calibrated hydrology subroutine. In the development of the vegetation subroutine, the calibration error was determined based on the percent of 500 m x 500 m cells that had a positive match (against observations) for species and the percent of cells that had a correct negative match. For this UA, a calibration error was estimated using the same data sets but for the percent of cells where the wetland type, not the species, was a correct match. The UA for the tenth variable listed above, the organic loading component of the annual accretion, was not based on the calibration error; rather, the UA for vertical accretion was based on uncertainty of organic matter (OM) and bulk density (BD) input data. This was derived from the range of data used to regionally estimate OM and BD based on wetland type.

3.0 Methodology

All phase 1 UA model runs used the same scenario values for the environmental drivers; the low scenario (S01) was selected as it resulted in less land loss than the other scenarios tested (Appendix C: Chapter 2). This enabled the response of land area to the UA to be better identified without having a higher rate of relative sea level rise overwhelm the model response to the uncertainty perturbations. The impact of a more severe environmental scenario upon model uncertainty was examined during the second phase of the UA and is described in a later section of this report.

The first phase of the UA was conducted on version 1 of the calibrated ICM, and the input variable values for the initial condition were not changed (Appendix C3-23: ICM Calibration and Validation). A perturbation term, ε, derived from the calibration error, was introduced to the targeted model variable after it is calculated within the associated subroutine but prior to use by the next subroutine. Only one model variable was perturbed per simulation, and the perturbation value was maintained throughout the 50-year simulation. Figure 1 illustrates how the perturbations were applied.

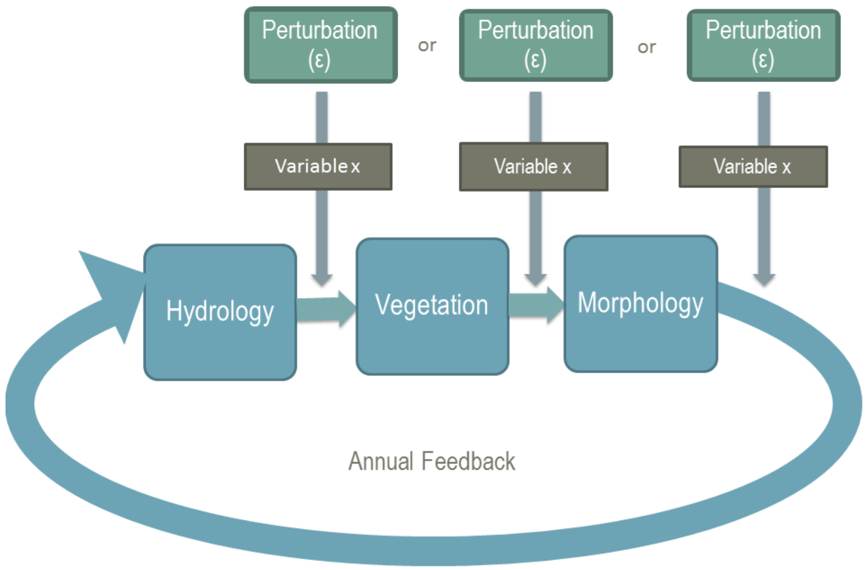

Figure 1: Conceptual diagram for Phase 1 parametric uncertainty approach.

For example, in the UA experiment where annual water level is perturbed at the end of year 1, the annual water level for each cell is perturbed by a specific amount (e.g., the +75 percentile). The increased water level values are then used in year 1 of the morphology subroutine to calculate whether the marsh collapse threshold has been exceeded. The values are also used in the vegetation model to determine which species are present, and thus which wetland type is dominant. This increase may or may not result in greater land loss in year 1. The landscape topography and bathymetry is updated accordingly and used as input for the hydrology calculations for year 2. The year 2 annual water level is calculated based on the model dynamics and year 2 boundary conditions. When the annual water level is passed to the morphology subroutine, it is perturbed again by the same magnitude. By applying the perturbation term 'between subroutines' as shown in Figure 1, the effects of the uncertainty in water level are included in the land calculation without altering the hydrology of the model. This approach focuses on the uncertainty of the targeted model variables and how it influences the key model output while sustaining the integrity of the model calibration since the perturbations are introduced after the targeted model variable is calculated in the relevant subroutine.

There are considerations that should be observed regarding the perturbation values used in the analysis:

- Perturbation values do not result in a non-physical or unnatural value for the variable under examination (e.g., negative salinity). If this occurred, adjustments were made to ensure a spread of values within the acceptable range was tested;
- For variables that were calibrated in a spatially variable manner, the perturbation values were also varied spatially. For example, the perturbation applied to salinity in a fresh environment was of different magnitude compared to saline areas; and
- Perturbations are constant in time. The magnitude of the perturbation was not adjusted from year to year during a 50-year simulation. Little is known about how the error would change with time, and as such, any temporal adjustment would be difficult to justify.

The next section provides the perturbation values used to perform the UA experiments.

3.1 Estimating the Perturbation Terms for Water Level, Salinity, and Total Suspended Solids

For annual water level, standard deviation of annual water level, two-week salinity, and TSS, a distribution of points around the mean was derived based on the statistical analysis performed during the calibration process. The two-week salinity comparison is a more stringent assessment on model performance than annual mean salinity (see Section 4.0). Therefore, all salinity perturbations throughout this analysis were based solely upon the two-week error values. The mean is the variable value used in the calibrated model, but a probability distribution of the error around the mean is not fully known; therefore, a normal distribution was assumed and used to calculate the +/- 25th and +/- 75th percentiles for both the RMSE and the MAE. The UA considered the composite uncertainty of multiple variables (the list of 10 variables provided above in Section 2.2). This led to the decision to select the 25th and 75th percentiles instead of a wider range (e.g., 5th and 95th percentiles). If a wider range is considered, the likelihood of occurrence of the 5th or 95th percentile of all model variables simultaneously is quite low. The 25th and 75th percentiles present a more likely space of occurrence.

The difference between the RMSE and MAE and whether one statistical tool is favorable over the other in terms of average model performance has been argued in literature (e.g., Willmott & Matsuura, 2005; Chai & Draxler, 2014). Although it is beyond the scope of this document to contribute to this debate, the MAE assigns a linear score where all individual differences are weighted equally in the average, while the RMSE gives a relatively high weight to large errors.

For this analysis, the MAE was used to estimate the perturbation values for all variables, with the exception of TSS, which had a much wider spread in error magnitudes. To account for the wide range in TSS values, the error was also adjusted as a percentage, rather than as a simple magnitude. This allowed for regions of the model with higher TSS concentrations to be perturbed by a value on the same order of magnitude as the predicted values. A similar approach was used for the salinity perturbations, but rather than a percent error term, the salinity observations were bracketed into four regimes, ranging from fresh to saline, so that the error in fresh areas would not unduly result in a lower magnitude of perturbation in the saline regions. Model performance for salinity was quantified for two different salinity calculations, annual mean salinity and the two-week mean salinity. Model performance was poorest when comparing the short-term two-week mean salinity to observed values, as compared to the long term annual calculations. Therefore, the larger error calculated from the two-week mean salinity was used for perturbations in this analysis. All salinity values used in the model (either long term salinity for the vegetation subroutine, or short-term salinity for wetland collapse thresholds in the morphology subroutine) were perturbed by the same salinity perturbation, which was set equal to the more conservative (e.g., higher) error estimated by the two-week mean salinity calibration error.

A set of experiments was designed (described in detail in Section 4 below), and the error terms used in the perturbations are summarized in Table 1.

Table 1: Error terms from the hydrology subroutine calibration period used to perturb the Integrated Compartment Model. (See Appendix C-23: ICM Calibration and Validation for error terms and discussion.)

Parameter	Units	Number of Observations	Mean Model Error		75th Percentile Perturbation
			Root Mean Square Error	Absolute Mean Error	
Annual Water Level	m	204	-	0.07	0.1
Annual Water Level Variability	m	204	-	0.018	0.03
Annual TSS	mg/L	146	25	-	70%
Salinity: 0-1	ppt	55	-	0.2	0.3
Salinity: 1-5	ppt	51	-	0.8	1.2
Salinity: 5-20	ppt	74	-	1.6	1.9
Salinity: 20-35	ppt	4	-	2.8	3.7

3.2 Estimating the Perturbation Terms of Wetland Types

During calibration of the vegetation subroutine, a percent correct match value for each year of the calibration period was determined for each wetland type. That percent is based on all the cells across the coast for which calibration data are available. These data could, theoretically, be used to perturb the model prediction of coverage area for each wetland type. One perturbation value could be chosen for each wetland type and at the end of each model year, the vegetation subroutine could adjust the cover of all species present that are classified as the perturbed wetland type (e.g., all species that are within the brackish wetland type) by the chosen perturbation value in each grid cell. While such an approach would be analogous to the perturbations made to the other model subroutines, the resulting vegetation coverages would not be consistent with the hydrodynamic conditions, resulting in the vegetation coverage simply reverting to the previously calculated vegetation coverage.

For example, consider the case where saline marsh coverage is to be perturbed in the negative direction, meaning decreasing their presence while the non-saline species would have their coverage increased. The model would convert saline marsh areas to non-saline types; however, during the next model year, the hydrodynamic conditions (e.g., salinity and water level variability) would still result in conditions in which the model would predict saline marsh was present. The vegetation model is a niche model that allows for the immediate establishment and growth of appropriate species for the current conditions (if they are within the dispersal distance); therefore, the perturbed output would simply revert to the vegetation type preferred by the model during the next model year.

The initial intent of this analysis was to determine the uncertainty associated with each model subroutine. However, the perturbation of the vegetation output would not be sustained unless the hydrodynamic model outputs are concurrently perturbed. In essence, perturbing the hydrodynamic model is sufficient to provide an idea about the impact and variability to the vegetation output. Specifically, the two primary drivers of the vegetation model, salinity and water level variability, were already included in this analysis. As will be shown in a later section, the perturbations of these two variables do not have a particularly large impact on the modeled coast wide land area, but they do result in different vegetation patterns. This provides an indirect approach to assess the impact of uncertain vegetation coverage on predicted land loss in the model. Therefore, the vegetation model output was not perturbed as part of this analysis.

3.3 Estimating the Perturbation Terms for Organic Loading

The accretion calculation within the morphology subroutine is derived from two sources: 1) the inorganic sediment load predicted by the hydrology subroutine and 2) the OM and BD values assigned to each marsh type (this is spatially varied across the coast). As discussed above, the uncertainty in the mineral depositional rates was perturbed based on the hydrology subroutine's TSS calibration statistics. The uncertainty in the organic component is not easily quantified from the measured Cesium cores used in the calibration of the subroutine. Therefore, in the UA, the organic portion of the accretion calculation was perturbed based on the variability of the measured OM and BD data used as model input. The organic accretion is directly proportional to the OM and BD values used; therefore, an analysis of the variability in these data results in a quantifiable range in the organic component of the vertical accretion rates.

The underlying dataset used to derive the OM and BD input data included not only mean values, but also standard deviations. The 25th and 75th percentiles of OM and BD input values were used to examine the uncertainty of the organic component of accretion calculations. The low BD values were paired with the high OM values to result in the maximum increase in vertical accretion calculations, and vice versa for the maximum decrease in accretion. The underlying dataset was summarized by basin and marsh type, which is the format that the model applies these organic loading rates, and therefore perturbation values vary spatially.

4.0 Experimental Design and Results – Phase 1

In the first set of experiments, only one variable was perturbed at a time. Table 2 shows the list of experiments performed. The first four experiments focused on perturbing the two-week salinity. Four perturbations were considered corresponding to +/- 25th and +/- 75th percentiles of the MAE distribution around the mean. Change in coastal land loss across the entire model domain, as compared against the "baseline" FWOA model run, is described below. Figures 2 and 3 show a very small change in total land area associated with +/- 25th perturbations (runs U01 and U02). Based on the outcome of the first four experiments, only +/- 75th percentiles of the MAE distribution were considered for the remainder of the variables. Also based on the outcome of these four experiments, a separate perturbation for the annual salinity was not performed; instead, the two-week salinity perturbation was used and applied to all salinity output (used in both the vegetation and morphology subroutines). If a separate annual perturbation was calculated, it would have been smaller than the two-week perturbation that was already tested. Clearly that would have resulted in less deviation from the "baseline" model run than what has been observed from the two-week salinity perturbations shown through the first four experiments. In addition to the first four experiments, eight experiments (two perturbations for each of the four remaining variables) were performed. The perturbation values are summarized in Table 2.

In all 12 experiments, one variable was perturbed at a time. The response of the model to these perturbations was analyzed through the total land area (across the entire coast) and land area in each ecoregion (spatial units identified within the ICM). The analysis also shows the behavior of the model response over 50 years, as the model output could potentially diverge from the "baseline" model run over time.

Table 2: Experimental runs – variables and individual perturbations.

Model Run	Perturbed Variable	Perturbation Magnitude
U01	Salinity	+ 25^{th} percentile
U02	Salinity	- 25^{th} percentile
U03	Salinity	+ 75^{th} percentile
U04	Salinity	- 75^{th} percentile
U05	Annual water level (m)	+ 75^{th} percentile
U06	Annual water level (m)	- 75^{th} percentile
U07	Annual water level variability (m)	+ 75^{th} percentile
U08	Annual water level variability (m)	- 75^{th} percentile
U09	Annual TSS (mg/l)	+ 75^{th} percentile
U10	Annual TSS (mg/l)	- 75^{th} percentile
U11	Organic sediment	More accretion (increased OM and decreased BD)
U12	Organic sediment	Less accretion (decreased OM and increased BD)

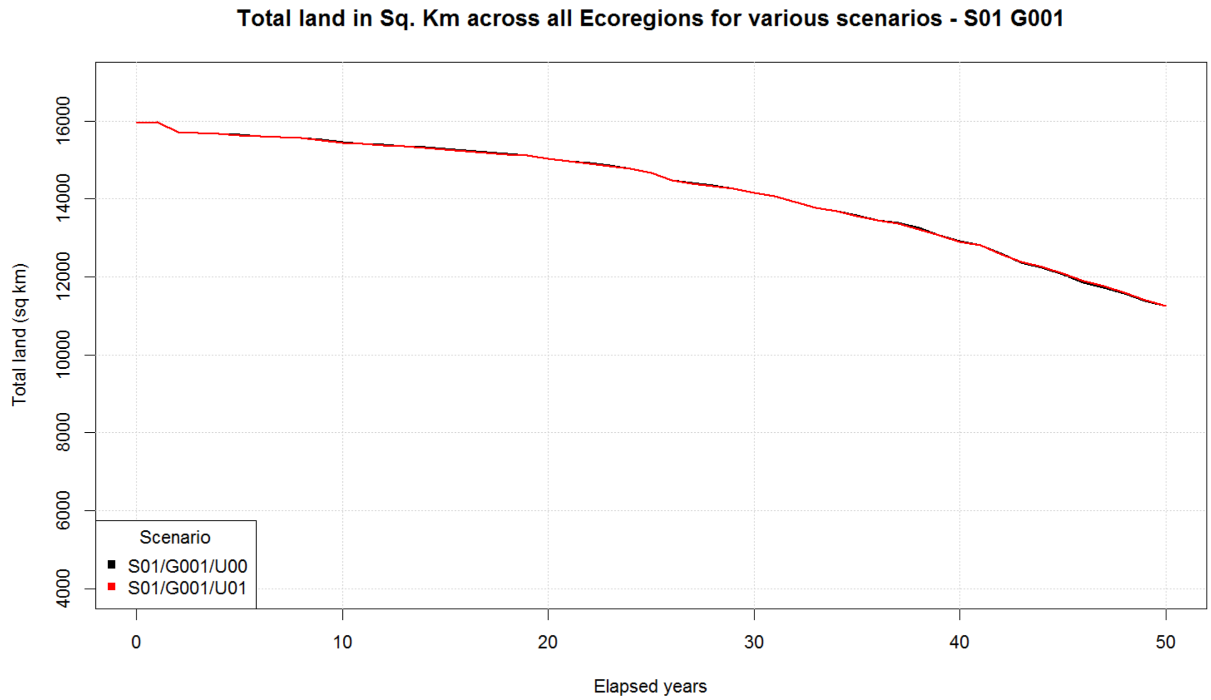

Figure 2: Total land change over time for U01. Salinity perturbed by +25th percentile run (red line) as compared to the baseline model run (FWOA - black line).

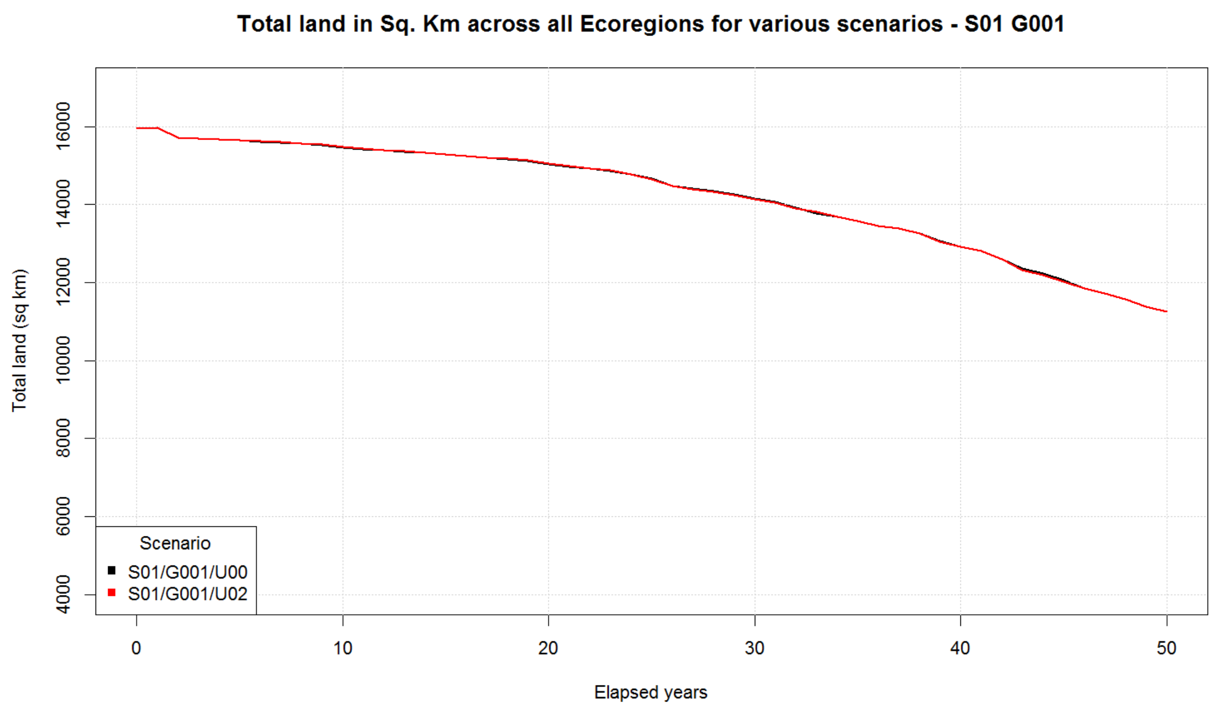

Figure 3: Total land change over time for U02. Salinity perturbed by -25th percentile (red line), as compared to the "baseline" model run (FWOA - black line).

4.1 Salinity Analysis

The salinity perturbations show a number of complex patterns. In the earlier years of the model run, an increase in salinity values (U03, Figure 4) resulted in slightly more land loss than the baseline model run; whereas, a decrease in salinity (U04, Figure 5) resulted in a slight decrease in land loss in earlier years. By the end of the 50-year simulation, however, the decreased salinity (U04) run resulted in more land loss than the baseline model run. The increased salinity run (U03) made up for the earlier losses and resulted in approximately the same amount of land loss by year 50 as the baseline model run. These more complex interactions are explained by the dual mechanisms in which salinity is used in the ICM land change algorithms. First, the long-term salinity values are used within the vegetation subroutine to determine what type of marsh is present. Second, the short-term, maximum two-week salinity is used within the morphology subroutine to collapse fresh wetlands that experience a salinity spike. Over time, an increase in the long-term mean salinity values results in the vegetation type converting from species on the fresher end of the spectrum to the more saline-tolerant species. These intermediate, brackish, and salt marsh species are therefore not subjected to the salt-spike collapse thresholds imposed by the morphology subroutine. If, however, the salinity values are decreased, the fresh wetlands remain fresh and are more exposed to salt-spike collapse thresholds during later years as the sea level rises, and the model domain becomes increasingly hydraulically connected.

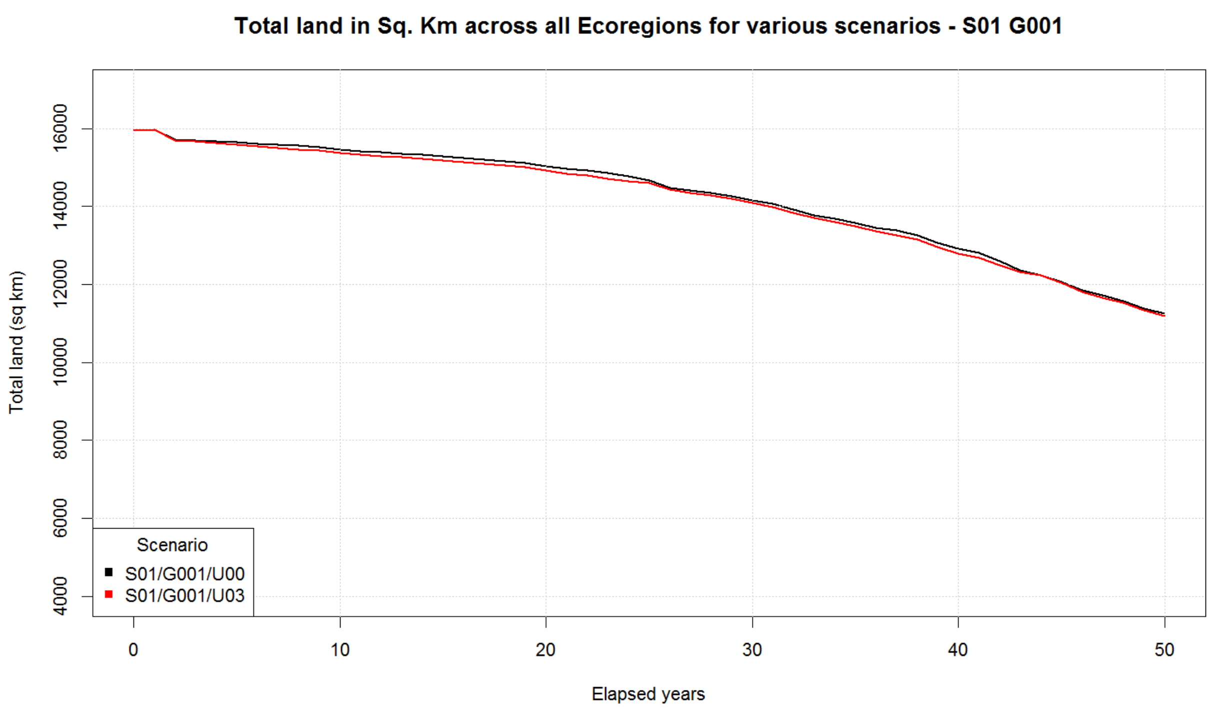

Figure 4: Total land change over time for U03. Salinity perturbed by +75th percentile (red line), as compared the baseline model run (FWOA - black line).

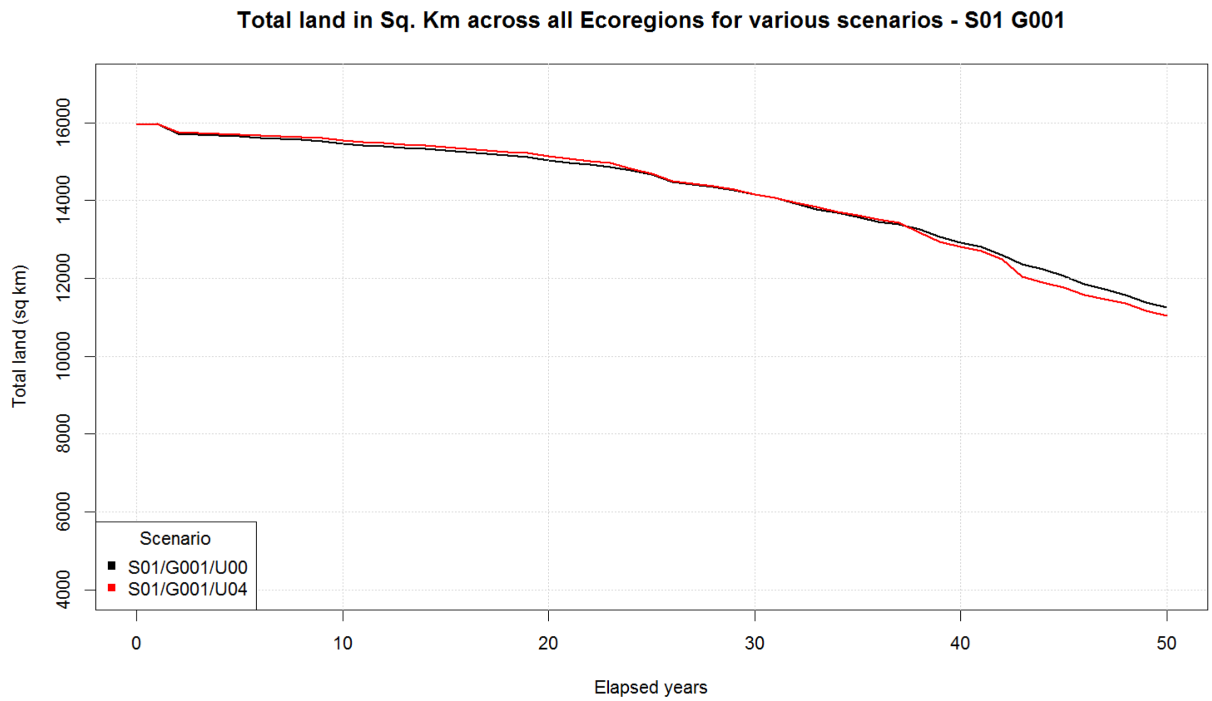

Figure 5: Total land change over time for U04. Salinity perturbed by -75th percentile (red line), as compared to the baseline model run (FWOA - black line).

4.2 Water Level Analysis

The mean water level perturbations, U05 and U06, resulted in the largest divergence from the baseline model run (Figures 6 and 7). The coast wide land loss divergence followed an intuitive response given that inundation is a key land loss mechanism in the ICM. The +75th percentile perturbation (U05), which perturbed the water level estimates upward, resulted in more land loss over time, whereas lowering the water level estimates using the -75th percentile perturbation (U06) maintained more land over the 50 year simulation. These results are consistent with those from the future scenarios analysis that indicate that coastal land area, as predicted by the ICM, is sensitive to varying rates of sea level rise (Appendix C: Chapter 2).

Increasing water level variability (run U07) resulted in slightly more land loss over time, but decreasing this parameter (run U08) did not have a large impact on the coast wide land loss calculations (Figures 8 and 9). The relatively minimal impact of these perturbations, on land area, is likely due to the small magnitude of the water level variability error term (+/- 0.03 meters at 75th percentile). This variable is only used within the vegetation subroutine and is on the same order of magnitude as the resolution of the vegetation subroutine input data. The probability of establishment and mortality of the individual vegetation species is provided in increments of 0.04 meters of water level variability. Therefore, perturbing the model output by the 75th percentile of the error is resulting in a very small adjustment to the establishment/mortality probabilities within the vegetation subroutine. These perturbations impacted the relative extent of specific vegetation types by the end of the model run (Figure 10 – vegetation at year 50); however, the magnitude of these changes in cover type did not substantially impact the coast wide area of land loss. While these perturbations did have some impact on vegetation type, and subsequently the collapse mechanisms driving land loss, the magnitude of these impacts were overwhelmed, at the coast wide scale, by other drivers of land loss throughout the 50-year simulation. In other words, the change in water level variability may change the vegetation type in the model, but the relatively minor differences in collapse mechanism between vegetation types was overwhelmed by the relative sea level rise throughout the model run.

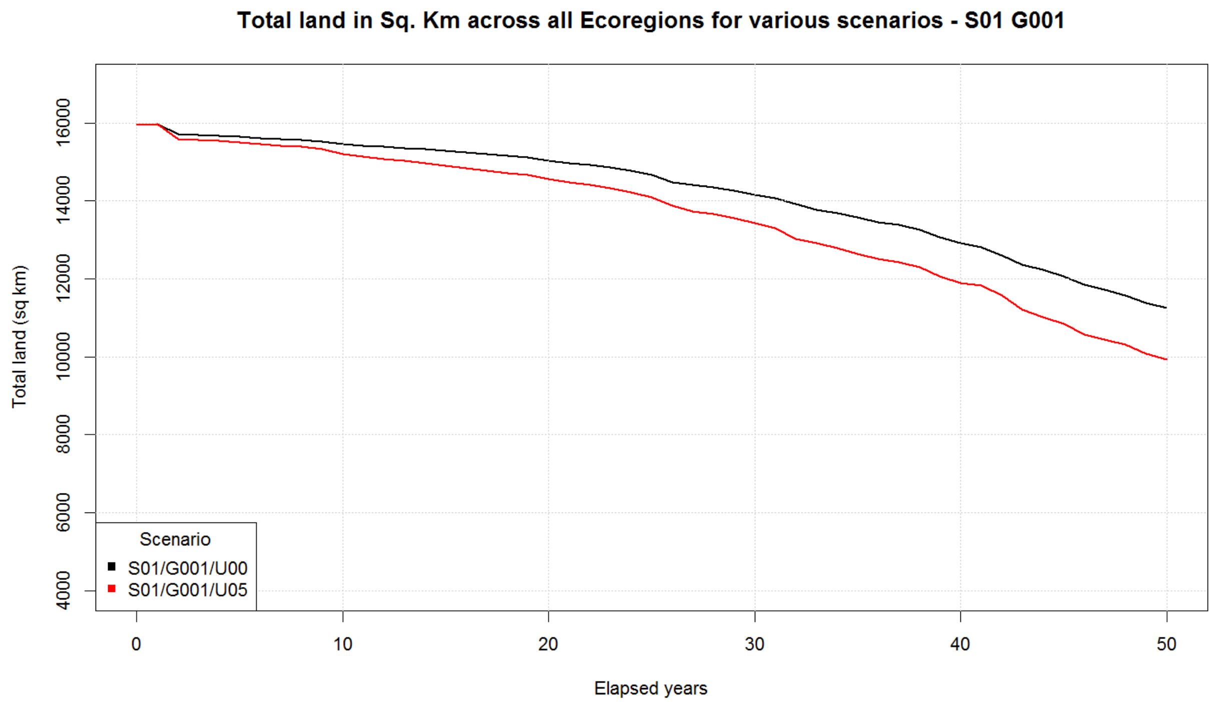

Figure 6: Total land change over time for U05. Annual water level perturbed by +75th percentile (red line), as compared to the baseline model run (FWOA - black line).

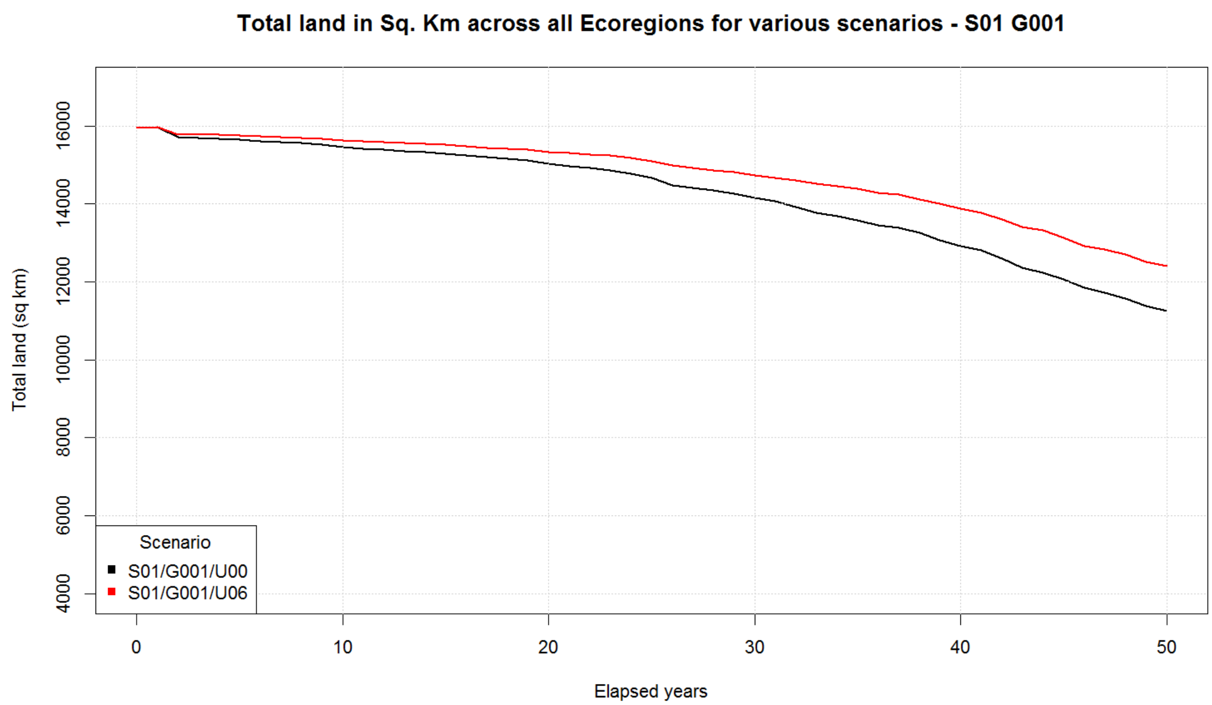

Figure 7: Total land change over time for U06. Annual water level perturbed by -75th percentile (red line), as compared to the baseline model run (FWOA - black line).

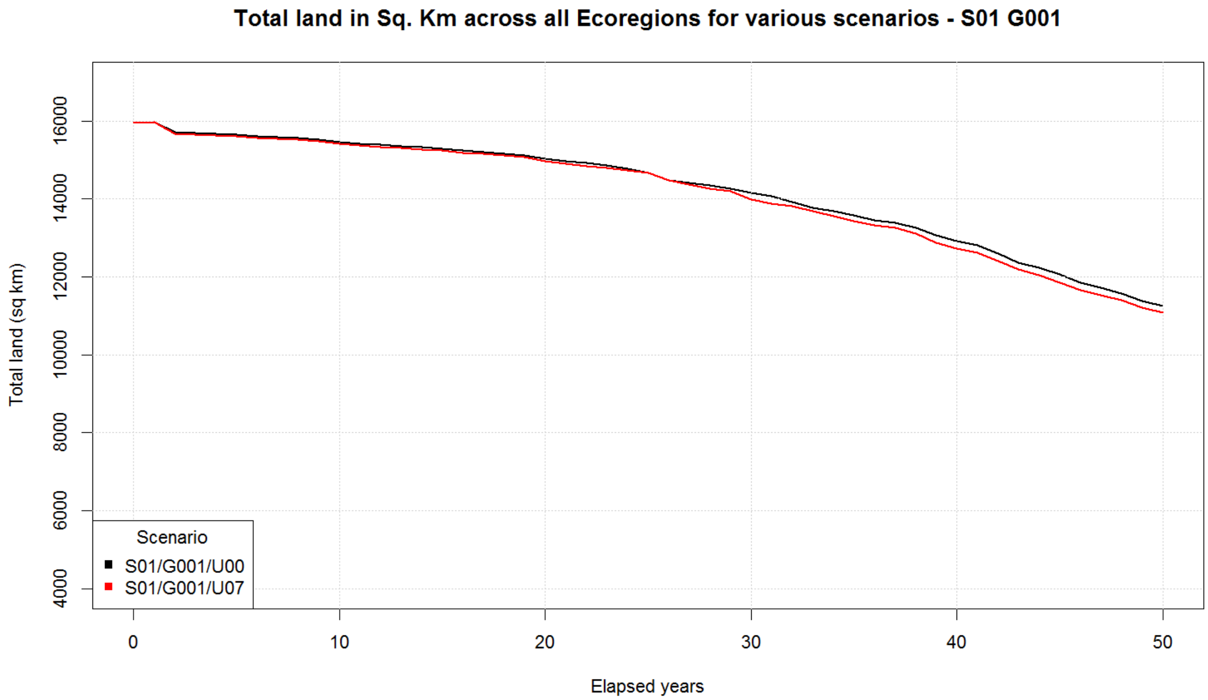

Figure 8: Total land change over time for U07. Annual water level variability perturbed by +75th percentile (red line), as compared to the baseline model run (FWOA - black line).

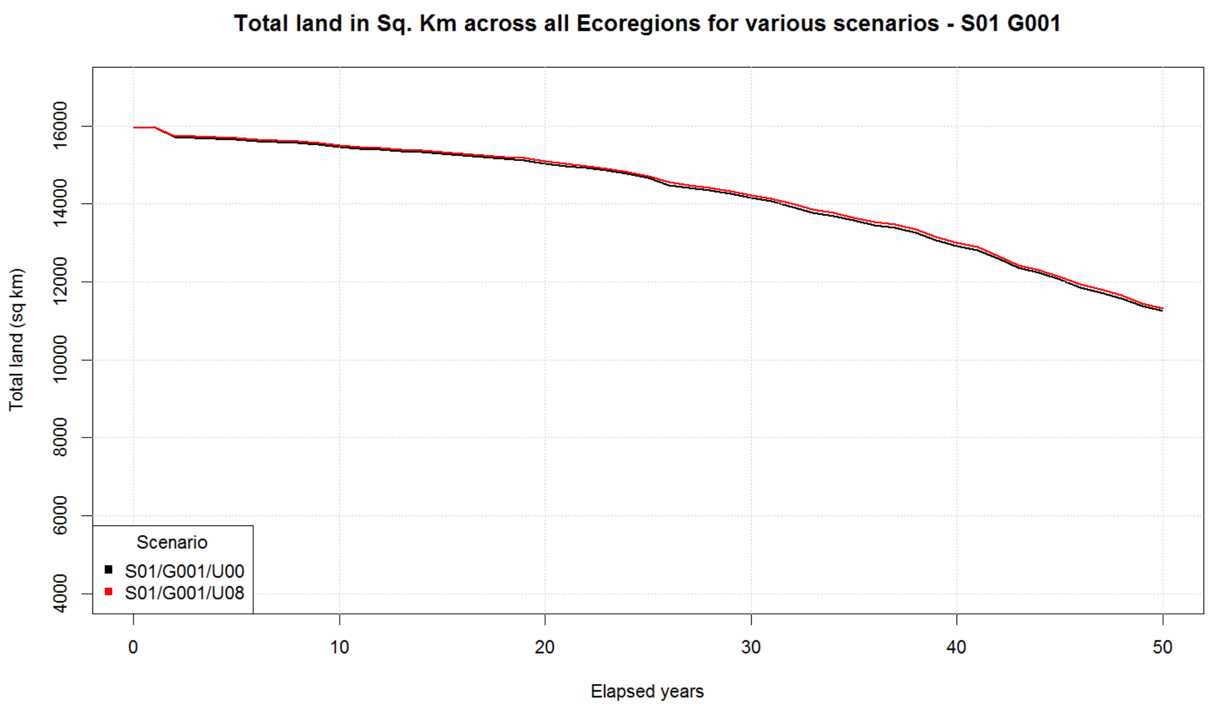

Figure 9: Total land change over time for U08. Annual water level variability perturbed by -75th percentile (red line), as compared to the baseline model run (FWOA - black line).

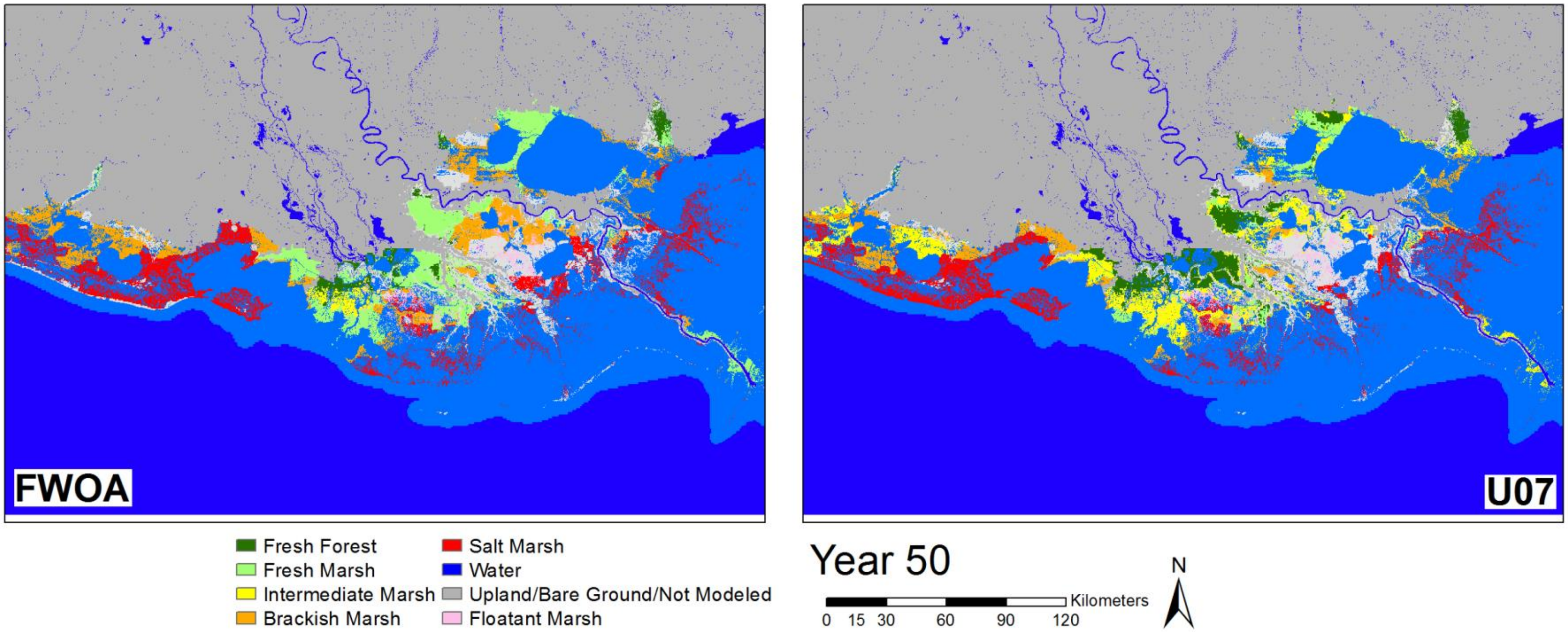

Figure 10: Relative abundance of vegetation types over the 50-year simulation; FWOA and U07 (+75th percentile of annual water level variability).

4.3 Total Suspended Solids Analysis

The coast wide land loss predictions appeared to be insensitive to perturbations to the annual inorganic TSS concentration that was perturbed in runs U09 and U10 (Figures 11 and 12). This can be explained by a number of factors. First, the TSS perturbation value (38 mg/L) was determined from the calibration error of a fairly small dataset. Both the observed and modeled TSS data varied by as much as an order of magnitude, and it is likely that the model area that would be most sensitive to a change in land area due to TSS perturbations would be the areas of the largest TSS concentrations. These areas are on the extremes of the TSS distribution and are therefore likely insensitive to just a +/- 75th percentile perturbation. Second, land gain in the model domain and in the real landscape (e.g., Wax Lake Delta) is occurring where there is a steady sediment supply from outside the system. The entrainment of estuarine bed sediments is not a large driver of land gain in coastal Louisiana (Burkett et al., 2007). Therefore, the inflow TSS boundary conditions are likely a much more sensitive parameter than the calculated TSS values from the deposition/resuspension routines in the hydrology subroutine. Third, the areas in the FWOA model run that experience land gain are limited. Overall, the impact of the TSS perturbations at the coast wide or ecoregion scales originates primarily from specific locations with definitive external sediment loading (e.g., Wax Lake Delta, West Bay, Big Mar, etc.) and ultimately did not result in significant response to the perturbations. It should be noted that the TSS perturbations might be important for certain project types such as large sediment diversions.

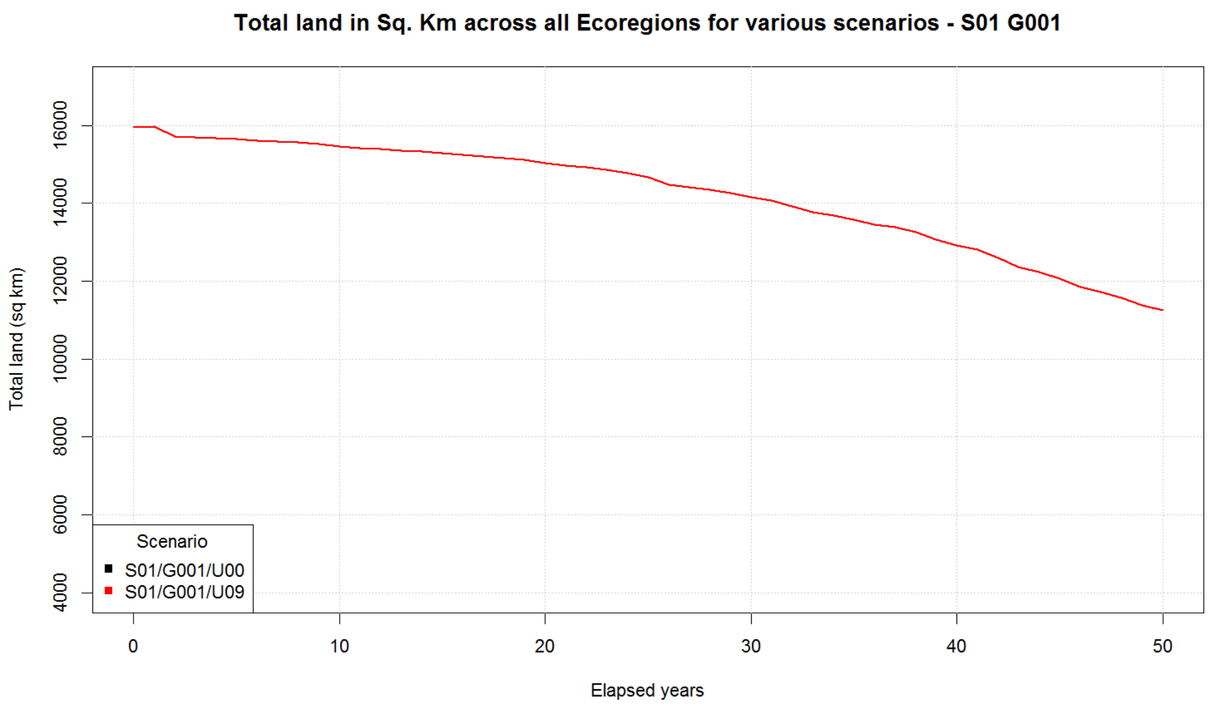

Figure 11: Total land change over time for U09. Annual inorganic TSS perturbed by +75th percentile (red line), as compared to the baseline model run (FWOA - black line).

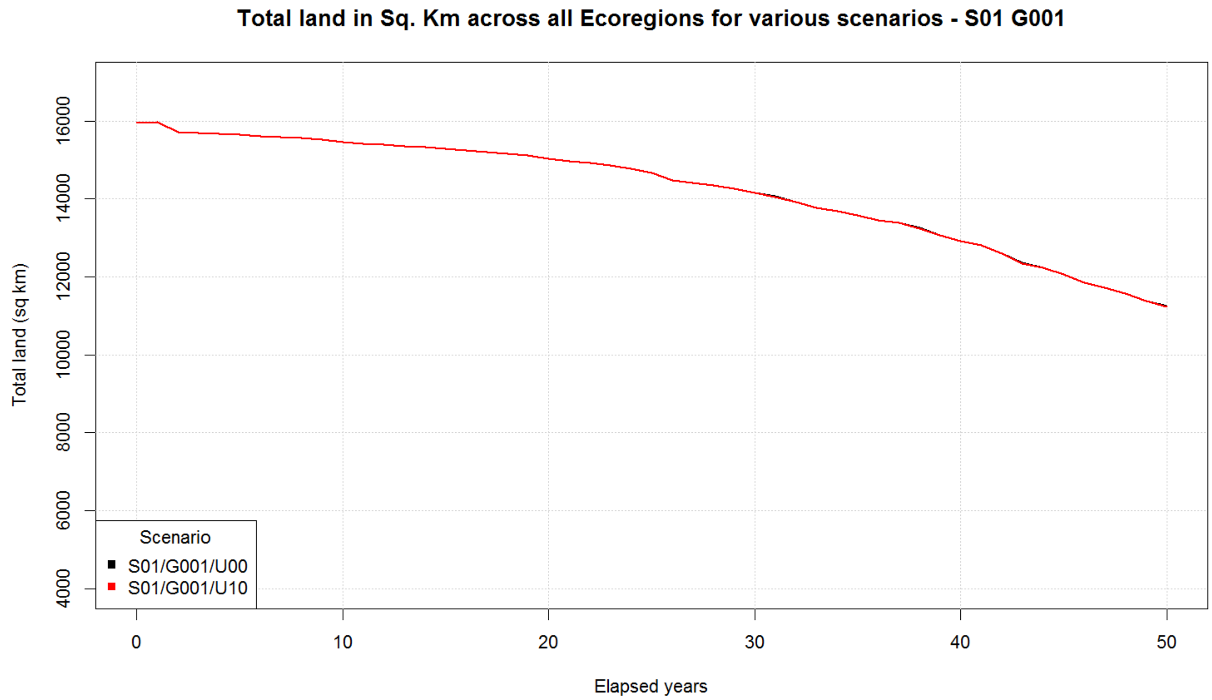

Figure 12: Total land change over time for U10. Annual inorganic TSS perturbed by -75th percentile (red line), as compared to the baseline model run (FWOA - black line).

4.4 Organic Sediment Analysis

Perturbing the organic accretion, as determined by OM input and BD values, resulted in an intuitive model response. Higher accretion due to high OM and low BD (run U11) resulted in a substantial increase in coast wide land area at year 50, as compared to the baseline model run (Figure 13). Conversely, run U12, which modeled lower accretion rates, resulted in a decrease in land area at year 50 (Figure 14). The impact of these perturbations on coast wide land area at year 50 is similar in magnitude to the mean water level perturbations (runs U05 and U06). However, the organic sediment perturbations are asymmetric around the baseline run. This asymmetry could be explained by areas of collapsed land in the baseline run that are close to but slightly above the collapse threshold in the baseline run. Once an area has collapsed, it will not be influenced by a decrease OM/BD; it simply remains collapsed. However, an increase to the OM/BD would sustain an area that was just on the threshold of collapsing/not collapsing, hence the asymmetry in the results.

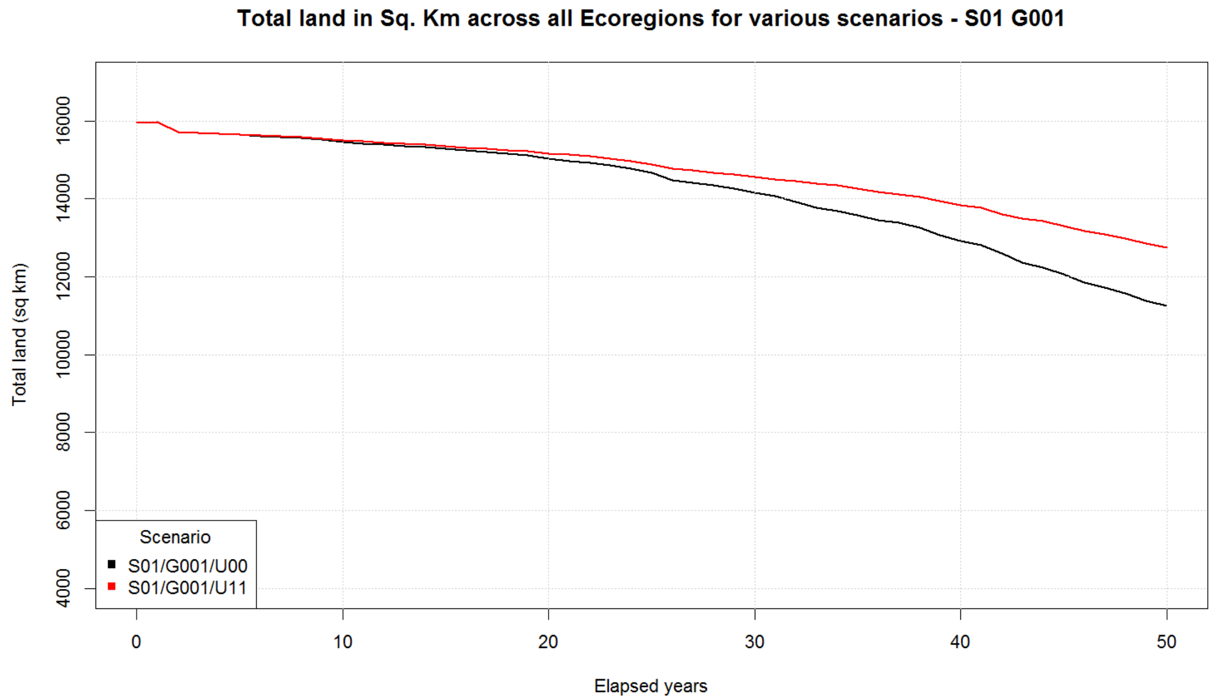

Figure 13: Total land change over time for U11. Organic sediment perturbed to increase accretion by increasing organic matter content and reducing bulk density values (red line), as compared to the baseline model run (FWOA - black line).

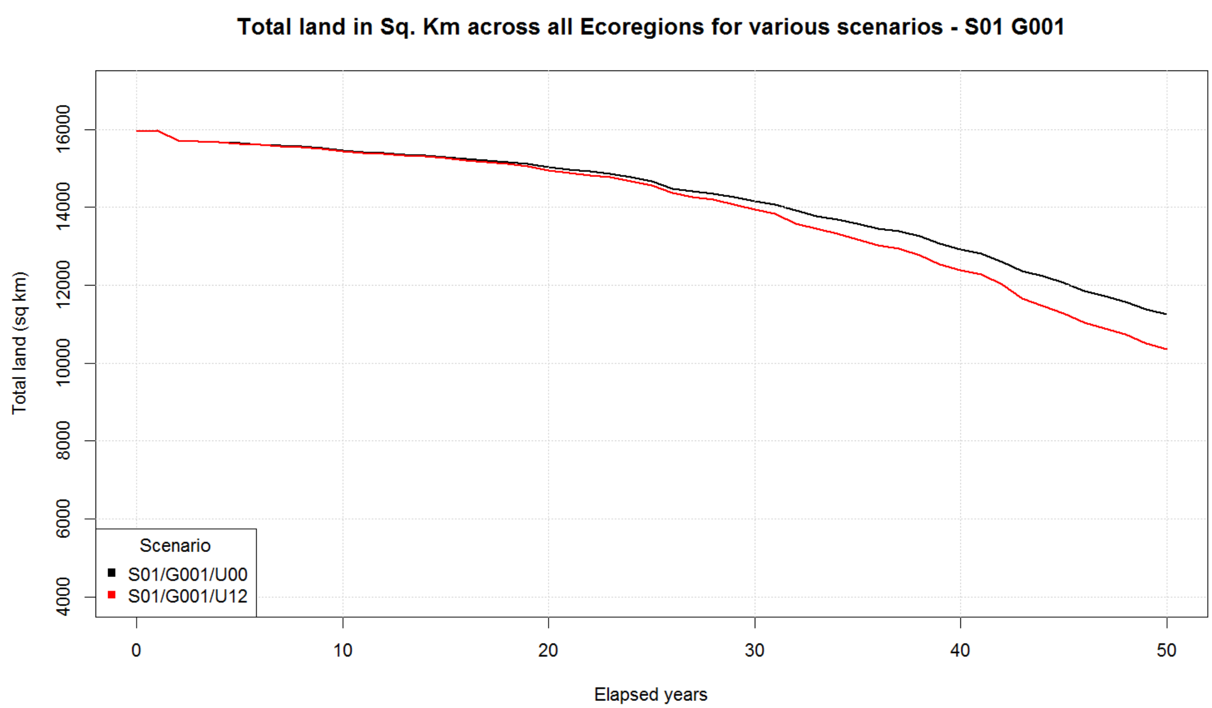

Figure 14: Total land change over time for U12. Organic sediment perturbed to decrease accretion by decreasing organic matter content and increasing bulk density values (red line), as compared to the baseline model run (FWOA - black line).

4.5 Composite Experiments

The initial set of experiments examined the individual perturbations of each variable. To explore the interdependence among these variables, a simulation was performed in which all the variables were perturbed at once. All the variables were concurrently perturbed using the +/- 75th percentile perturbations. Two "composite" simulations, U21 and U22, were designed such that they would produce the largest and smallest land area coast wide. For this to be accomplished, the sign of the perturbation for each variable was selected based on the response of the initial adjustments of the 10 non-vegetation simulations (U03-U12). For example, all the experiments that individually resulted in more land area than the baseline (U00) model run were combined and used simultaneously in experiment U21. Similarly, all experiments that individually resulted in less coast wide land area than the baseline model run were combined in experiment U22. The exact combinations of values for these runs are provided in Table 3.

The results from these two composite runs, U21 and U22 (Figure 15), can be used to bracket the uncertainty in land area over time as compared to the baseline case of FWOA under the low future environmental scenario (S01).

Table 3: Composite experimental runs.

Model Run	Composite Perturbation	Perturbation Variable	Perturbation Value
U21	Composite perturbations - low (minimum land coast wide at year 50)	Salinity	Same as U04
		Mean Water Level	Same as U05
		Water Level Variability	Same as U07
		Annual TSS	Same as U10
		Organic sediment	Same as U12
U22	Composite perturbations - high (maximum land coast wide at year 50)	Salinity	Same as U03
		Mean Water Level	Same as U06
		Water Level Variability	Same as U08
		Annual TSS	Same as U09
		Organic sediment	Same as U11

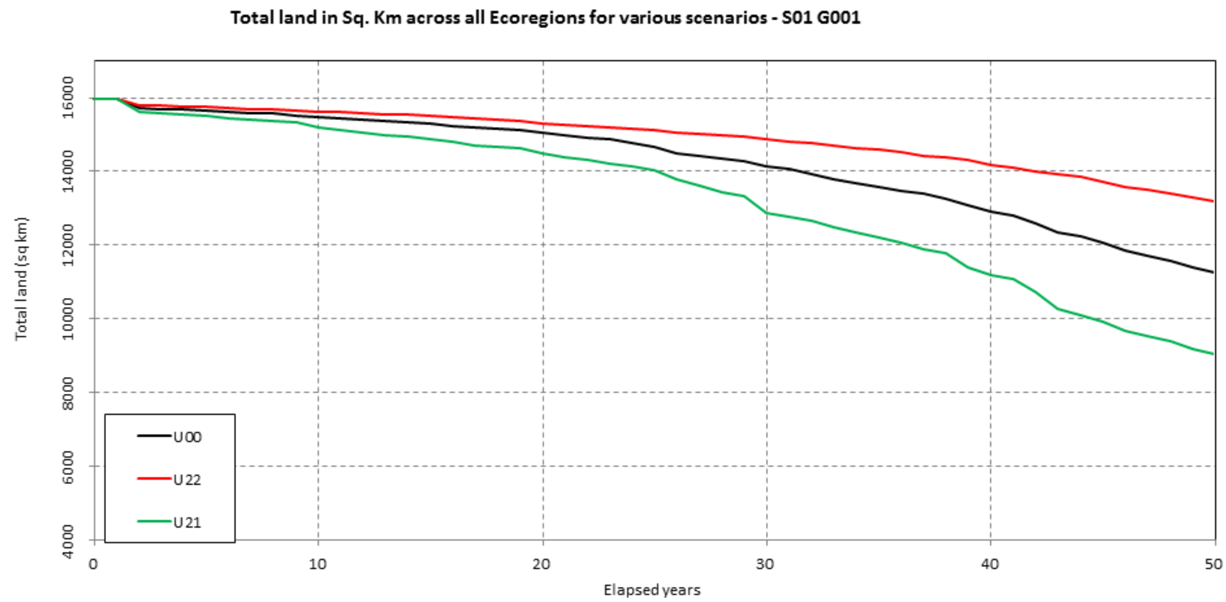

Figure 15: Total land change over time for U21 (green line) and U22 (red line). The composite uncertainty runs provide the upper and lower limits on model uncertainty, as compared to the baseline model run (FWOA - black line).

5.0 Spatial Analysis of Uncertainty – Phase 1

Figures 2 through 15 show the magnitude of uncertainty in land area over time, but they do not indicate the spatial distribution of uncertainties. To examine where the ICM was more (or less) certain in predicting land gain or loss over time, the results of 10 individual perturbations (U03 through U12) discussed earlier (see Table 2) were combined into a spatial dataset that determined how often an individual land/water pixel (30 m x 30 m) was classified as land or as water at year 50. This was then compared against the year 50 classification from the baseline FWOA run (U00) to determine a relative certainty around the year 50 prediction of land or water at each 30 m pixel (Figure 16). The green regions in Figure 16 represent pixels that were classified as water during FWOA at year 50, but were more likely to be predicted as land in the perturbation runs (U3-U12). The darker the green, the more often it was classified as land indicating a higher level of uncertainty that the FWOA prediction of water would, in fact, be water. Contrarily, the red regions in Figure 16 represent pixels that were predicted to be land at year 50 in FWOA U00, but were more often predicted to be water during the perturbation runs (U3-U12). Again, the darker the shade of red, the higher the uncertainty around the FWOA prediction that a given land pixel at year 50 would in fact be land. Regions that are gray (land) or blue (water) in Figure 16 indicate pixels that, regardless of the perturbation applied, are consistently predicted to be the same classification at year 50 as the FWOA baseline run. These gray and blue regions, taken together, represent the area within the model domain that is consistently predicted as either land or water during all individual perturbation simulations conducted for this analysis.

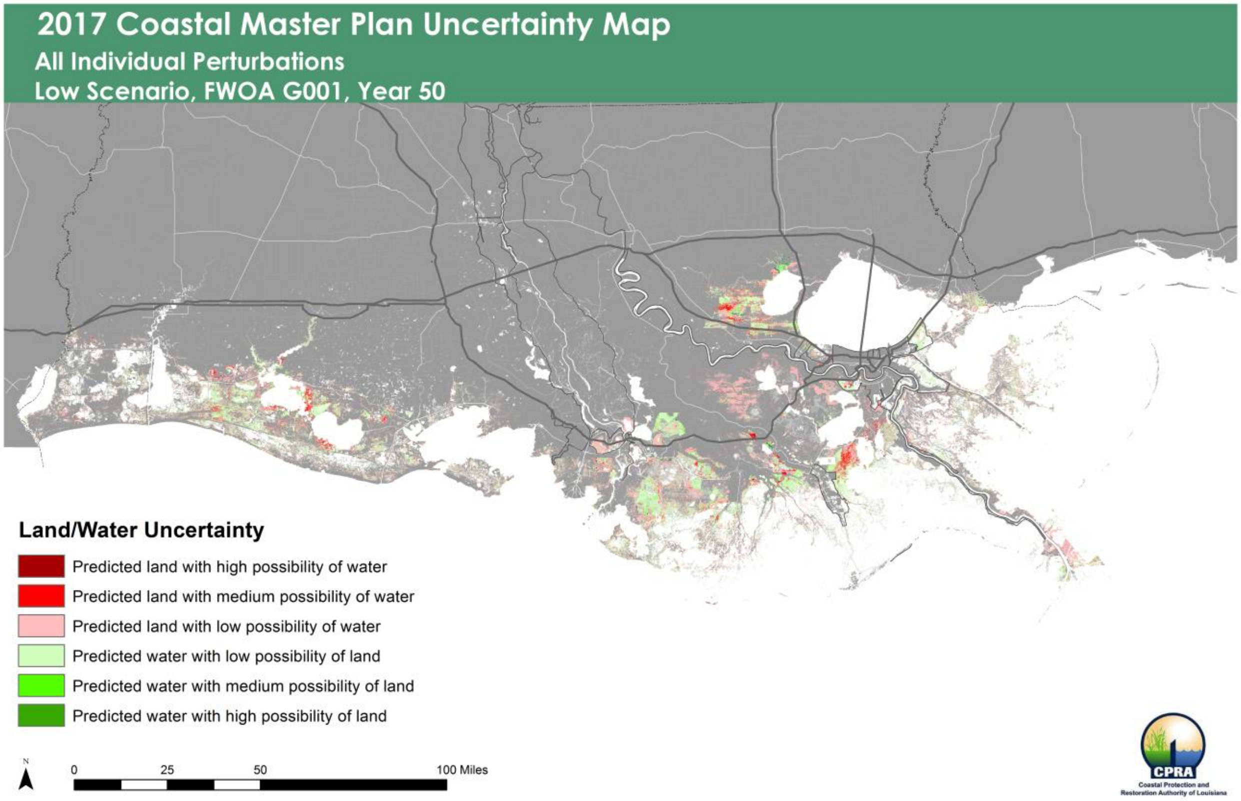

Figure 16: Land/water prediction uncertainty – all individual perturbations at year 50.

The regions where the perturbed runs consistently result in a year 50 land/water value different than the FWOA U00 case (dark green and dark red) indicate that there are many land/water pixels that are consistently impacted by perturbations. These are the pixels that are close to a collapse threshold in the baseline run (U00). Once perturbed, it is quite likely for these pixels to result in a different outcome at year 50, regardless of the perturbation applied. The regions that are seldom different from the baseline (light green and light red), on the other hand, indicate pixels that respond to one (or two) very specific perturbations only. Based upon the magnitude of impact from the individual runs, it is likely that these pixels of lower uncertainty are 'activated' into losing or sustaining land when the mean water level or the organic accretion perturbations are applied. Physically, these are the only two perturbed variables that will directly influence the elevation and could result in these changes.

A composite run in which the mean water level and the organic accretion are perturbed in opposite directions (e.g., lower mean water level, higher organic accretion, and vice versa), will potentially have a synergistic effect on land pixels that are lost or sustained. Figure 17 shows that this synergistic effect does indeed take place when the variables are perturbed simultaneously. The purple regions in Figure 17 are pixels that are land at year 50 from the composite run, U22, that were water in all individual perturbation runs as well as the FWOA baseline.

Some of the land/water pixels that did not change from their baseline condition during the individual perturbations did respond to the composite runs of U21 and U22. Thus, a complete set of composite perturbations needed to be analyzed to determine if U21 and U22 bracket the uncertainty in coastal land area over time.

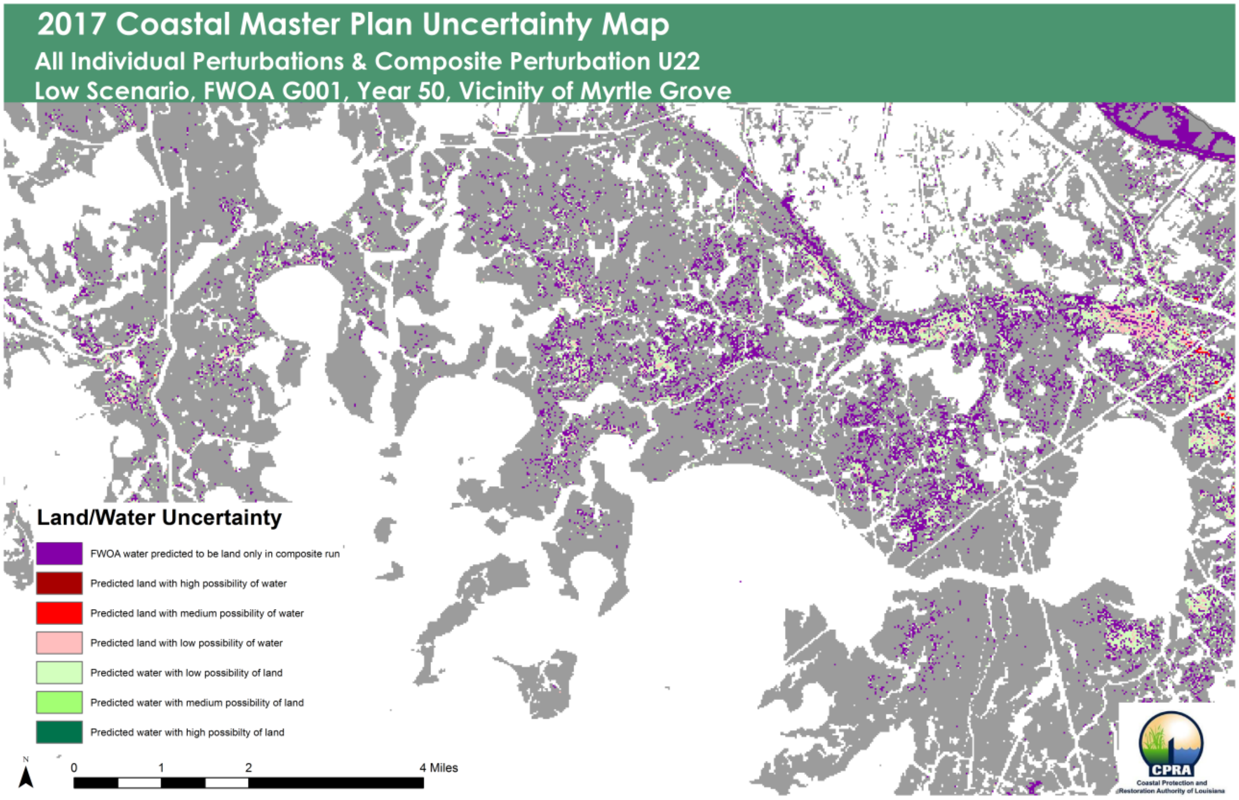

Figure 17: Land/water prediction uncertainty – all individual perturbations and composite run U22 (near Myrtle Grove, year 50).

From the individual perturbation runs (U09 and U10), it was determined that errors in suspended inorganic sediments (TSS) did not result in any appreciable change in coast wide land area over time. Removing TSS from further analysis allowed for 16 additional simulations that would test model uncertainty as a function of all possible permutations of two perturbed values for mean water level, salinity, water level variability, and organic accretion. These 16 permutations (Table 4) were analyzed, allowing for a thorough determination of uncertainty in the FWOA land/water predictions and the relative sensitivity to the different perturbation permutations.

Table 4: Experimental runs – composite perturbations – all permutations.

Model Run	Salinity	Mean Water Level	Water Level Variability	Organic Sediment
U25	+75 percentile	+75 percentile	+75 percentile	+OM/-BD
U26	+75 percentile	+75 percentile	+75 percentile	-OM/+BD
U27	+75 percentile	+75 percentile	-75 percentile	+OM/-BD
U28	+75 percentile	+75 percentile	-75 percentile	-OM/+BD
U29	+75 percentile	-75 percentile	+75 percentile	+OM/-BD
U30	+75 percentile	-75 percentile	+75 percentile	-OM/+BD

Model Run	Salinity	Mean Water Level	Water Level Variability	Organic Sediment
U31	+75 percentile	-75 percentile	-75 percentile	+OM/-BD
U32	+75 percentile	-75 percentile	-75 percentile	-OM/+BD
U33	-75 percentile	+75 percentile	+75 percentile	+OM/-BD
U34	-75 percentile	+75 percentile	+75 percentile	-OM/+BD
U35	-75 percentile	+75 percentile	-75 percentile	+OM/-BD
U36	-75 percentile	+75 percentile	-75 percentile	-OM/+BD
U37	-75 percentile	-75 percentile	+75 percentile	+OM/-BD
U38	-75 percentile	-75 percentile	+75 percentile	-OM/+BD
U39	-75 percentile	-75 percentile	-75 percentile	+OM/-BD
U40	-75 percentile	-75 percentile	-75 percentile	-OM/+BD

After completion of these 16 permutations, the output from U31 was compared to U22. The only difference between these two composite perturbation runs was the inclusion of TSS perturbation in U22; all other perturbed variables were identical between U22 and U31. As Figure 18 shows, there was some impact at very small scales (e.g., near Davis Pond); however, at a coast wide scale, there were only negligible differences between these two composite perturbations. Therefore, the inclusion of TSS perturbations was determined to be unnecessary in assessing overall model uncertainty.

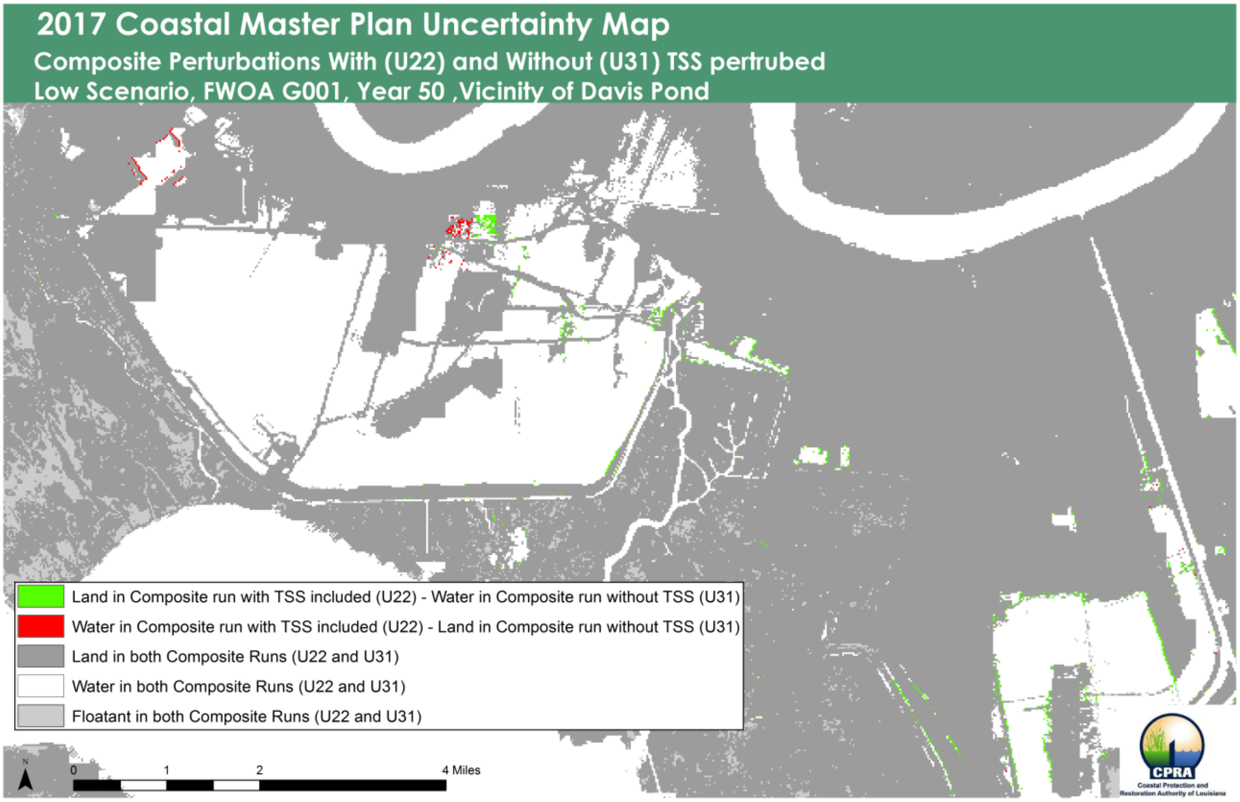

Figure 18: Land/water prediction uncertainty – composite perturbations with (U22) and without perturbed TSS (U31); near Davis Pond, year 50.

As predicted by analyzing the pixels affected by the composite run U22, but none of the individual perturbations (Figure 17), the range in land area change over time is highly sensitive to perturbations to mean water level and organic accretion. In Figure 19, the four runs that result in the highest land area over time (U29, U31, U37, and U39) all included a decrease in mean water level and an increase in organic accretion. The salinity and water level variability perturbations appear to drive a difference in vegetation cover, though if the mean water level and organic accretion perturbation counteract one another, the salinity and water level variability perturbations do appear to have some impact on the final land area. However, regardless of the exact combination, all of these runs appear to result in slightly more land at year 50 than the baseline U00 run.

If the mean water level is increased at the same time as the organic accretion is decreased (U26, U28, U34, and U36), it does not appear as if the exact combination of salinity and water level variability makes much of an impact. The final land area in the last decade of these model runs is remarkably consistent, indicating more loss coast wide than the U00 FWOA baseline run.

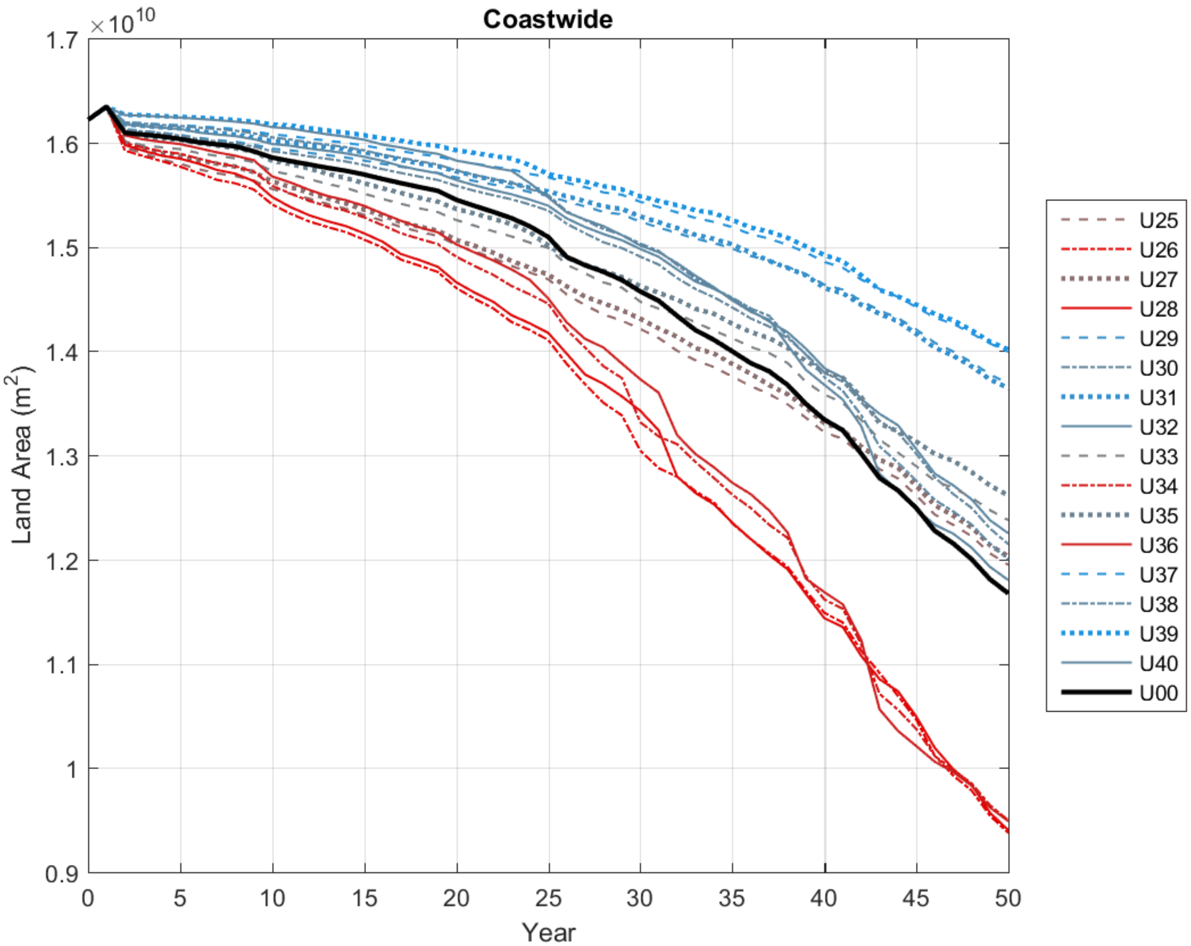

Figure 19: Baseline FWOA land area over time (U00, black line) compared against all 16 permutations of composite uncertainty perturbations.

6.0 Assessing Future Without Action Model Uncertainty Under the High Environmental Scenario – Phase 2

6.1 Methodology for Assessing Spatial Patterns of Uncertainty – Phase 2

In addition to the temporal and spatial assessment of overall parametric uncertainty, the outputs from the FWOA analysis provided in the previous sections helped to identify the key model variables with significant impact on land area and to examine sensitivity to change of the perturbation terms for each variable. This examination was then used to design a streamlined UA for application under a more severe future scenario, as well as the uncertainty in land predictions of the implemented 2017 Draft Coastal Master Plan. Based on the results previously presented, it appears that the interdependency among the model variables is important (Figure 19). Therefore, the 16 permutations presented in Table 4 and Figure 19 were applied to the two high scenario FWOA analyses (i.e., from version 1 and version 3 of the ICM) and the high scenario 2017 Draft Coastal Master Plan analysis conducted in the second phase of the UA.

The overall spatial patterns of model uncertainty across the coast from each of the four cases (i.e., the three high scenario simulations just discussed and the low scenario FWOA from ICM version 1) are shown in Figure 20 through Figure 23. For visualization purposes, each land/water pixel was classified with a relative sense of uncertainty. This relative uncertainty was determined for each set of 16 permutations. The more often a permutation resulted in a land/water pixel having a different outcome at year 50 than the baseline (U00) case, the higher the relative uncertainty for that pixel. If a land/water pixel was predicted to be different than the baseline case in 6% or less of the permutations (e.g., no more than one of the 16 permutations resulted in a different outcome at year 50) that land/water pixel was classified as being either certain land or certain water. A land/water pixel that returned a year 50 result that differed from the baseline in 6-37% of the permutations (two to six of the 16 permutations) was considered to have a *low possibility* of having a different outcome compared to the baseline run. Differences from baseline in 38-69% of the permutations indicated a *medium possibility* of a different outcome than baseline, and any pixel that was different from the baseline in more than 69% of the permutations was classified as having a *high possibility* of having a year 50 value that differed from the baseline run.

Hypothetically, if the following maps were solid red, this would indicate that all land predicted to be remaining at year 50 was in fact uncertain and all permutations resulted in a prediction of less land at year 50 than the baseline. If the maps were solid green, this would indicate that all areas predicted to be water at year 50 would in fact be predicted as land under all other non-baseline cases. As Figure 20 through Figure 23 show, the patterns are mixed and vary between both the environmental scenarios and the FWOA or Draft 2017 Coastal Master Plan conditions that are modeled. In simple terms, more red on the map implies that the model overestimates land area, and more green implies that the model underestimates land area.

6.2 Comparison Between Low and High Scenarios

The impact upon model uncertainty between the low and high scenarios is shown by comparing the low and high scenario analyses that were conducted using ICM_v1 (S01 G001 and S03 G001, respectively). The similarities and differences in spatial variability of these relative uncertainties are evident in Figure 20 and Figure 21. The portion of the model domain west of Vermilion Bay appears to be a region of variable uncertainty under the low scenario (Figure 20); a relatively large portion of this area is sensitive to differing outcomes under the 16 permutations. Either regions of baseline-predicted land are repeatedly predicted as water under the uncertainty permutations (red pixels) or baseline-predicted water repeatedly is predicted to be land under the permutations (green pixels). This indicates a region of the model that is (more or less) symmetric around the baseline run; which is also evident in the time series of land area predicted under all permutations in the western region (see Figure 34 through Figure 37 for ecoregions west of the Atchafalaya Basin). Under the high scenario (Figure 21), however, large portions of the domain are not as varied at year 50 across the 16 permutations as they were under the low scenario. Much of the area that is consistently predicted under the high scenario is due to that fact that much more area is predicted to be water at year 50 under the high scenario in the baseline run and in each permutation. While there are some regions of baseline-predicted water that have a low possibility of being predicted land under the permutations, some visually prominent features are: the baseline-predicted area of land along the Gulf shoreline south of Vermilion Bay, Grand Lake, and White Lake that has a high possibility of being water under the permutations and the variable uncertainty of the Maurepas swamp area under the low scenario that is much less uncertain under the high scenario. These changes in uncertainty are largely the result of how the ICM_v1 algorithm treats bare ground that is not suitable for any modeled vegetated and the salinity predictions of ICM_v1. Version 3 of the ICM (ICM_v3) addressed these issues and is detailed in the following section.

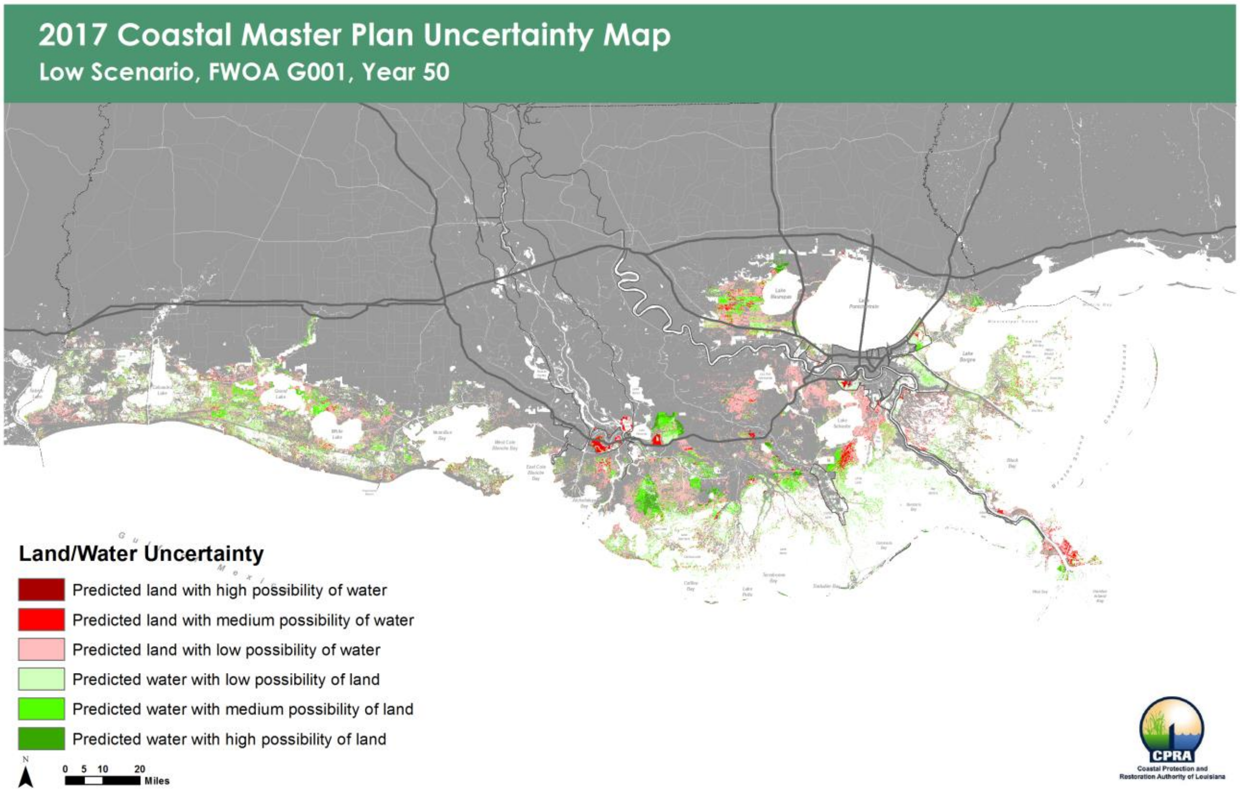

Figure 20: Relative uncertainty in baseline FWOA predictions under the low scenario using version 1 of the ICM (S01 G001).

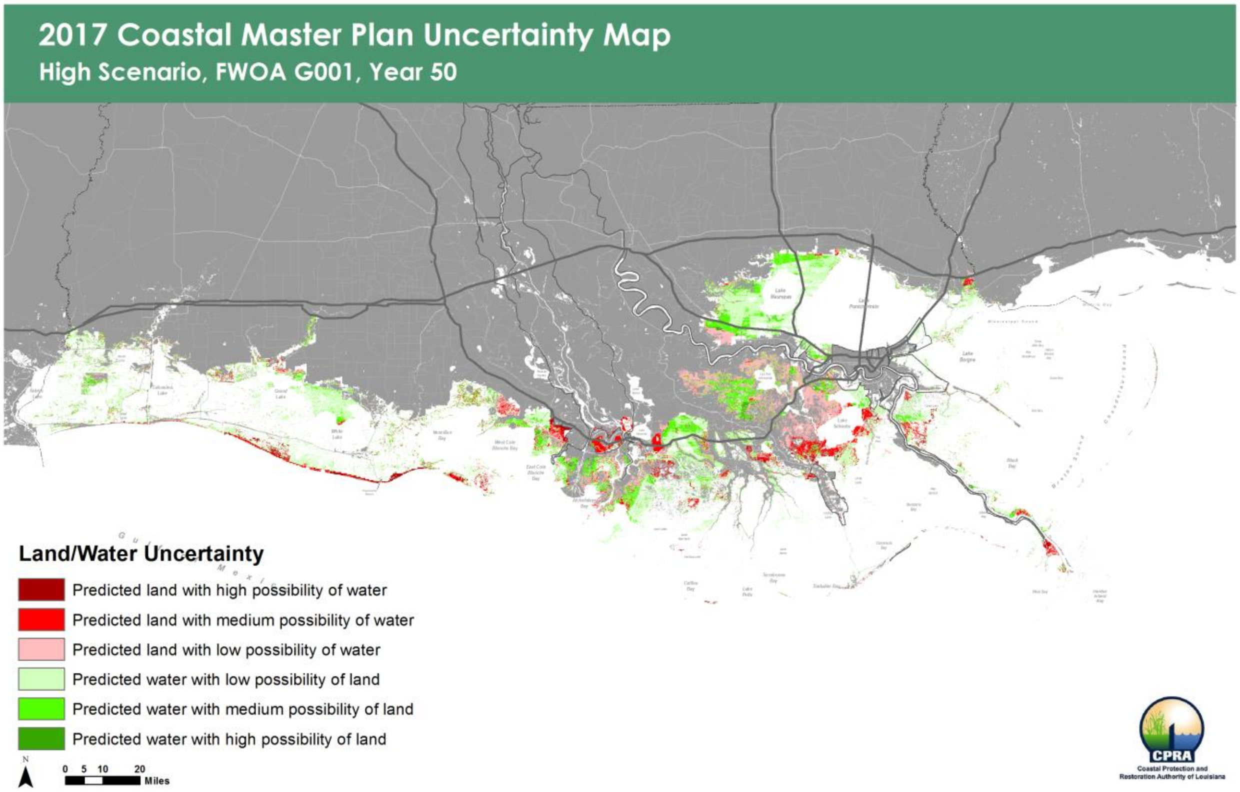

Figure 21: Relative uncertainty in baseline FWOA predictions under the high scenario using version 1 of the ICM (S03 G001).

6.3 Comparison Between ICM Versions 1 and 3

Upon the completion of the project-level runs for the 2017 Coastal Master Plan analysis, several adjustments were made to the ICM code to address various model instabilities and unrealistic model behaviors under a few select conditions. The two main changes that impacted the model uncertainty results were a recalibration of salinity transfer in some of the large model compartments in the fresh upstream regions and a change that allowed for areas of persistent bare ground (where conditions are not suitable for any modeled vegetation species to be present) to collapse into open water if repeatedly inundated by the annual mean water level. These changes are discussed in detail in Attachment C3-22: Integrated Compartment Model (ICM) Development and Attachment C3-23: ICM Calibration, Validation, and Performance Assessment.

The ability of inundated bare ground to collapse into open water impacts the uncertainty analysis results in three particular areas of the model domain. First, the Gulf shoreline south of Vermilion Bay, Grand Lake, and White Lake are modeled as baseline-predicted land in ICM_v1; however, they have a relatively high possibility of being water under the permutations (Figure 21). Once the bare ground is allowed to collapse in ICM_v3, these ridges are persistently predicted to be water at year 50 (Figure 22); a change from high uncertainty in ICM_v1 to low uncertainty in ICM_v3. The other two areas impacted by the bare ground collapse change are in Upper Barataria in the vicinity of Lake Bouef and in Breton Sound. Again, in ICM_v1, these regions were persistently predicted to be bare ground in the last few model years (due to a rise in salinities beyond the tolerance range of any nearby vegetation species) and were subsequently predicted to be land at year 50 in nearly all permutations (Figure 21). Under

ICM_v3, these areas were subjected to collapse if persistently non-vegetated; this resulted in these areas of baseline-predicted land now with a high possibility of being water (Figure 22).

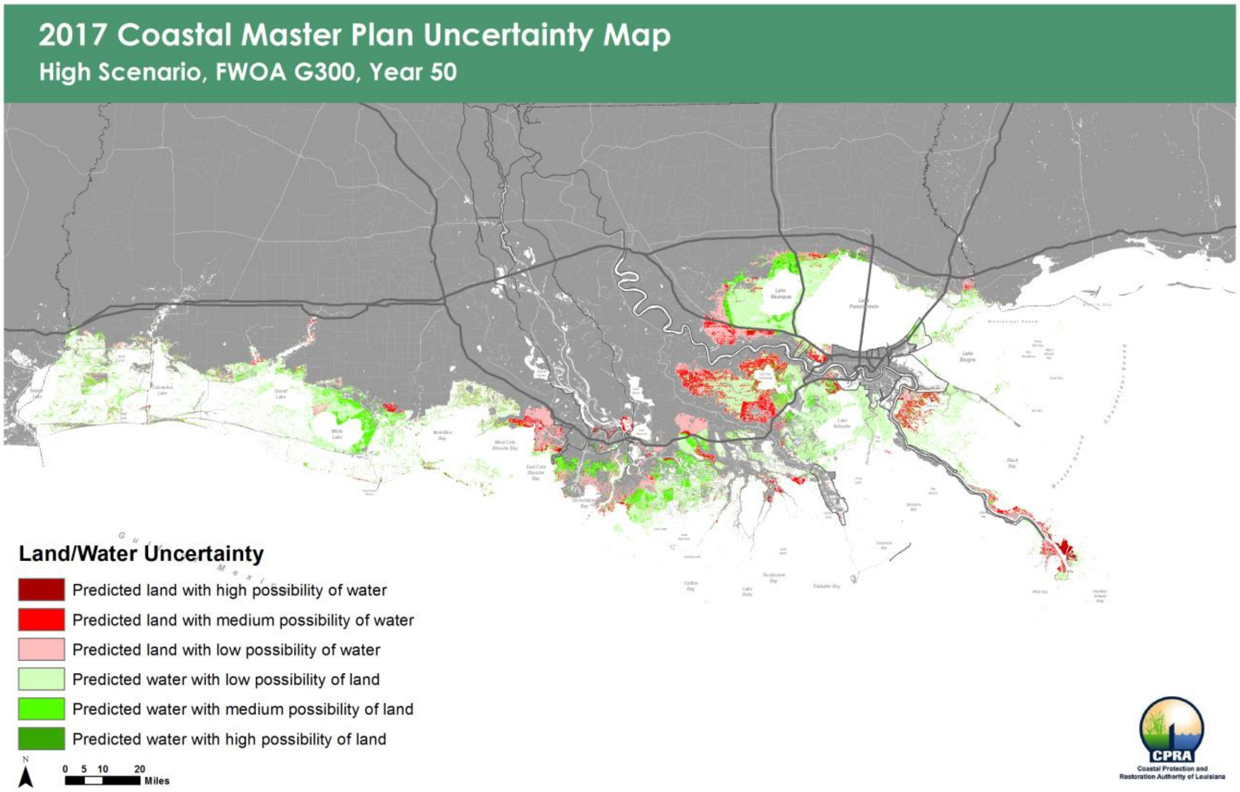

Figure 22: Relative uncertainty in baseline FWOA predictions under the high scenario using version 3 of the ICM (S03 G300).

The change to salinity calculations made between ICM_v1 and ICM_v3 had a more subtle effect on the spatial patterns of model uncertainty, with almost all differences occurring in the Upper Pontchartrain ecoregion (upstream of Lake Maurepas) and in the Upper Barataria ecoregion (upstream and around Lac des Allemandes). The changes in the Maurepas region are primarily due to areas that were predicted to be water at year 50 under nearly all ICM_v1 permutations (white or light green pixels south of I-10 in Figure 21), but were predicted to be land with a low to medium possibility of being water under the ICM_v3 permutations (pink or red pixels south of I-10 in Figure 22). The Upper Barataria region had a much clearer response to the ICM_v3 changes. The improved representation of salinity in this region under ICM_v3 resulted in a more consistent response than under ICM_v1, with a low to medium possibility that the baseline-predicted land in this region would be water under the uncertainty permutations. The changes made to salinity calculations between ICM_v1 and ICM_v3 resulted in more stable salinity calculations in these upstream areas, which in turn resulted in fewer salinity spike events in ICM_v3. Under ICM-v1, the relatively unstable salinity calculations resulted in a greater number of perturbations resulting in loss of fresh wetland area due to salinity-induced collapse. The unstable salinity spiking issues of ICM_v1, therefore were more certain than ICM_v3, yet unrealistically resulting in land loss. The update made to ICM_v3, therefore returned more realistic and stable salinity results in upstream basins but more variability in land/water predictions at year 50.

7.0 Assessing Model Uncertainty Under the Future With Action Draft Master Plan

7.1 Spatial Patterns of Future With Draft Master Plan Uncertainty

The 16 uncertainty permutations were also performed for the Draft 2017 Coastal Master Plan under the high scenario (S03 G400). In the region of the model domain west of the Atchafalaya Basin, there were a few distinct differences in spatial patterns of uncertainty as compared to the high scenario FWOA using ICM_v3 (S03 G300) (Figure 23). Namely, there are large areas under the Future With Draft Master Plan that are predicted to be land under all (or all but one) permutations. These large, irregular, gray-colored polygons (e.g., around Calcasieu Lake and on Marsh Island) are in fact the location of numerous marsh creation projects that are implemented in the western region in the Draft 2017 Coastal Master Plan. These permutations indicate that, as implemented in the Draft 2017 Coastal Master Plan, these projects will perform consistently across the uncertainty permutations. In addition to the numerous marsh creation projects in the western region that are consistently predicted to be land at year 50, east of Calcasieu Lake, outside of any direct project footprint, there is an increase in the amount of baseline-predicted water area that has a low to medium possibility of being land.

Like the FWOA uncertainty, an expanse of baseline-predicted water in Central and Western Terrebonne appears to have a low to medium possibility of being land. However, the Draft 2017 Coastal Master Plan includes diversion projects off the Atchafalaya River that maintain land in this region; the FWOA baseline-predicted water with low possibility of being land in Central Terrebonne south of Amelia (Figure 22) becomes baseline-predicted land with a low possibility of being water under the Draft 2017 Coastal Master Plan (Figure 23). Additional changes in this central region include several large areas of marsh creation projects. Some of these marsh creation projects are predicted to be land under nearly all permutations, while others are baseline-predicted land at year 50 with some possibility of being water under specific uncertainty permutations. A large marsh creation project further east at the border between Terrebonne and Barataria ecoregions demonstrates the same trend of being baseline-predicted land with a low to medium possibility of being water at year 50 under the Draft 2017 Coastal Master Plan.

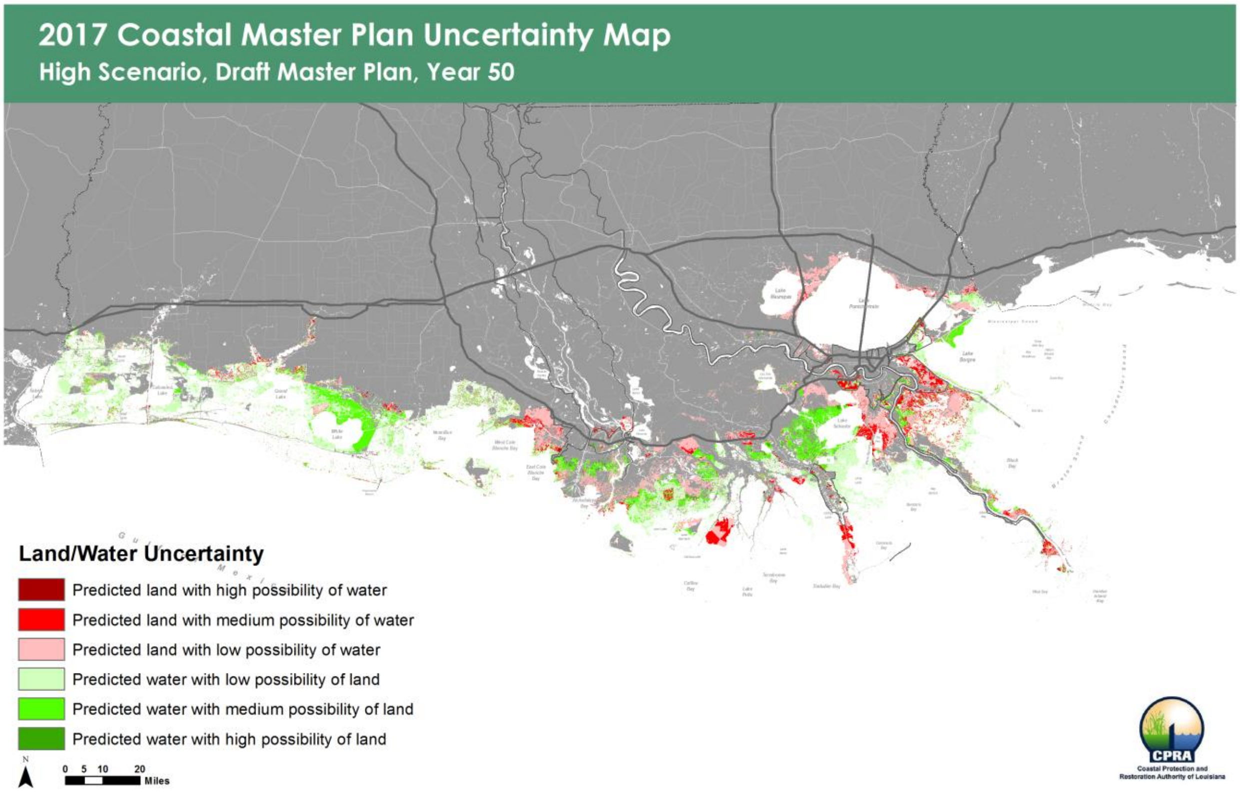

Figure 23: Relative uncertainty in baseline Future With Draft Master Plan predictions under the high scenario using version 3 of the ICM (S03 G400).

Elsewhere in the eastern region of the model domain, the starkest difference between the Draft 2017 Coastal Master Plan and the FWOA are in the upper portions of the Barataria and Pontchartrain basins. Almost all baseline-predicted land in Upper Barataria north of Highway 90 is land in nearly all uncertainty permutations. The same behavior is seen upstream of Lake Maurepas, nearly all baseline-predicted land remains land under all permutations. Both regions were relatively uncertain under the FWOA (Figure 23); this change in behavior is largely due to the presence of freshwater diversions into the Maurepas swamp area as well as the presence of the Lake Pontchartrain Barrier (001.HP.08) hurricane protection project (see Section 5.3.2.3 in Chapter 4). There is some uncertainty regarding the baseline-predicted land in the Maurepas landbridge area under the Draft 2017 Coastal Master Plan; however, this was predicted to be water with a low possibility of being land under the FWOA.

Uncertainty in the areas impacted by Mississippi River diversions varies; immediately adjacent to the outfalls of both Mid-Barataria and Mid-Breton Diversions, the land built or sustained by the diversion is maintained under all permutations. In Breton, there is a section of baseline-predicted water near, but not immediately adjacent to the outfall, that has a high possibility of being land under the uncertainty permutations. Areas of sustained land further afield in Breton are baseline-predicted land under the Draft 2017 Coastal Master Plan with a low to medium possibility of being water. A portion of the most Gulf-ward fringe marsh areas in Breton Sound are predicted to be water under the baseline Draft 2017 Coastal Master Plan; however, they have a low possibility of being land under certain permutations. This complex behavior in Breton Sound is evident in the time series plots of land area over time shown in Figure 28, where uncertainty expands over time under the Draft 2017 Coastal Master Plan.

The uncertainty within the Barataria Basin has a more distinct response than that of Breton Sound. The areas of baseline-predicted land under the Draft 2017 Coastal Master Plan to the north of the Mid-Barataria Diversion near Lafitte have some uncertainty when perturbed and have a low to medium possibility of being water. The opposite effect is seen on the far western side of Barataria; a large portion of baseline-predicted water to the north and west of Lake Salvador has a medium to high possibility of being land under the permutations. Similarly, a large area of baseline-predicted water surrounding Little Lake has a low possibility of being land under the permutations (Figure 23).

7.2 Magnitude and Temporal Behavior of Uncertainty

The previous sections detail the spatial patterns of uncertainty under the various permutations modeled. Not only did the spatial distribution of uncertainty change under different environmental scenarios and futures with or without projects, but the magnitude and temporal behavior of the uncertainty also varied. The absolute range in uncertainty for each of the four perturbation sets previously discussed in Section 6 are shown in Figure 24. For this analysis, the absolute range in uncertainty was calculated at each year by subtracting the minimum land area for the year from all 16 permutations from the maximum land area from the 16 permutations. The permutation resulting in the maximum and minimum area may change from year to year; therefore, for any given year, the magnitude of the uncertainty range shown in Figure 24 is the difference between the uppermost and lowermost curves at the respective year as shown in Figure 25. By year 50, the uncertainty range for the low scenario FWOA from version 1 of the model (which was discussed at length in Sections 0, 4.0 and 5.0 of this report) is as great or greater than all of three of the permutation sets subjected to the high scenario. Over time, the uncertainty under the low scenario steadily increases; whereas, under the high scenario the range in uncertainty eventually decreases (to varying degrees) in the last simulation decade. This behavior is due to the predicted land area being very sensitive to the high rates of eustatic sea level rise and subsidence under the high scenario. The uncertainty introduced by the variable perturbations is overwhelmed by these conditions; whereas, under lower rates of sea level rise and subsidence, the model is relatively more sensitive to the perturbed variables.

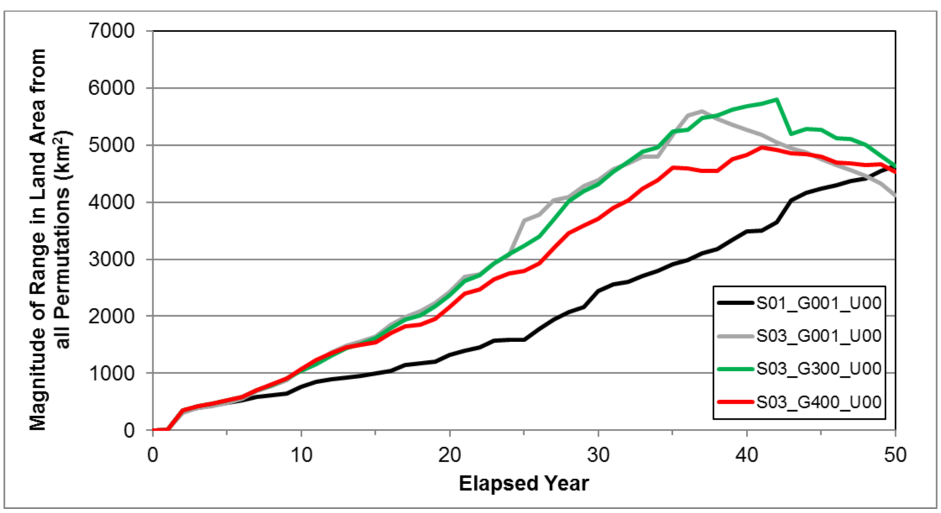

Figure 24: Range in coast wide land area prediction from all permutations under low scenario FWOA_v1 (S01_G001: black line), high scenario FWOA_v1 (S03_G001: gray line), high scenario FWOA_v3 (S03_G300: green line), and high scenario Draft Master Plan (S03_G400, red line).

In the lower basins such as Lower Pontchartrain (Figure 27), Lower Barataria (Figure 31), and Lower Terrebonne (Figure 32) as well as the Chenier Ridge ecoregions in the western part of the domain (Figure 36 and Figure 37), the FWOA predictions of land area asymptotically approach a given area, regardless of the perturbed variables. Not all of the basins converge as strongly as others, but this overwhelmingly consistent behavior results in the decrease in uncertainty range seen under the two high scenario FWOA permutation sets. Conversely, as the Draft 2017 Coastal Master Plan predicts a general increase in land area over time, there is more land area available to be uncertain about; however, there is still a decrease in the width of uncertainty around the baseline Draft 2017 Coastal Master Plan over the last decade.

In general, there are two predominant behaviors in the land area time series curves presented in the following figure: the first is a relatively linear response of land area over time, and the second is a non-linear (e.g., step-wise) response in which a large collapse event is triggered in a single year. The first response, a smooth and continuous reduction over time is the result of inundation collapse mechanisms in which the increasing rates of relative sea level rise over time continuously inundate the coastal wetlands. Inundation collapse within the ICM is only initiated if the wetland surface is persistently inundated to a depth greater than the collapse threshold depth for two back-to-back years. This collapse mechanism is, therefore, representative of continuous trends and the resulting land area response is a continuous, linear relationship. The second, step-wise, response is due to singular events impacting large portions of marsh. This is triggered solely by salinity-induced collapse of fresh wetland areas due to a short term spike in salinity. This step-wise collapse event can only occur on fresh wetlands, and is therefore more evident in regions of the coast dominated by fresh wetland systems, in particular the Upper Pontchartrain and Upper Barataria ecoregions (Figure 26 and Figure 30, respectively).

In summary, the magnitude and behavior of land area in coastal Louisiana predicted by the ICM varies both spatially and temporally under a wide set of perturbations to model input and output variables. Throughout all of the uncertainty analysis runs conducted, the total range of land area was 9,400 km^2 to 14,000 km^2, with a baseline prediction of 11,700 km^2 under the low scenario FWOA using ICM_v1. Under the high scenario, using ICM_v1, the land area ranged from 4,000 km^2 to 8,200 km^2, with a baseline prediction of 5,300 km^2. Under the high scenario, using ICM_v3, the land area ranged from 4,000 km^2 to 8,700 km^2, with a baseline prediction of 5,600 km^2. Finally, under the high scenario using ICM_v3, the Draft 2017 Coastal Master Plan the land area ranged from 6,800 km^2 to 11,300 km^2, with a baseline prediction of 8,600 km^2.

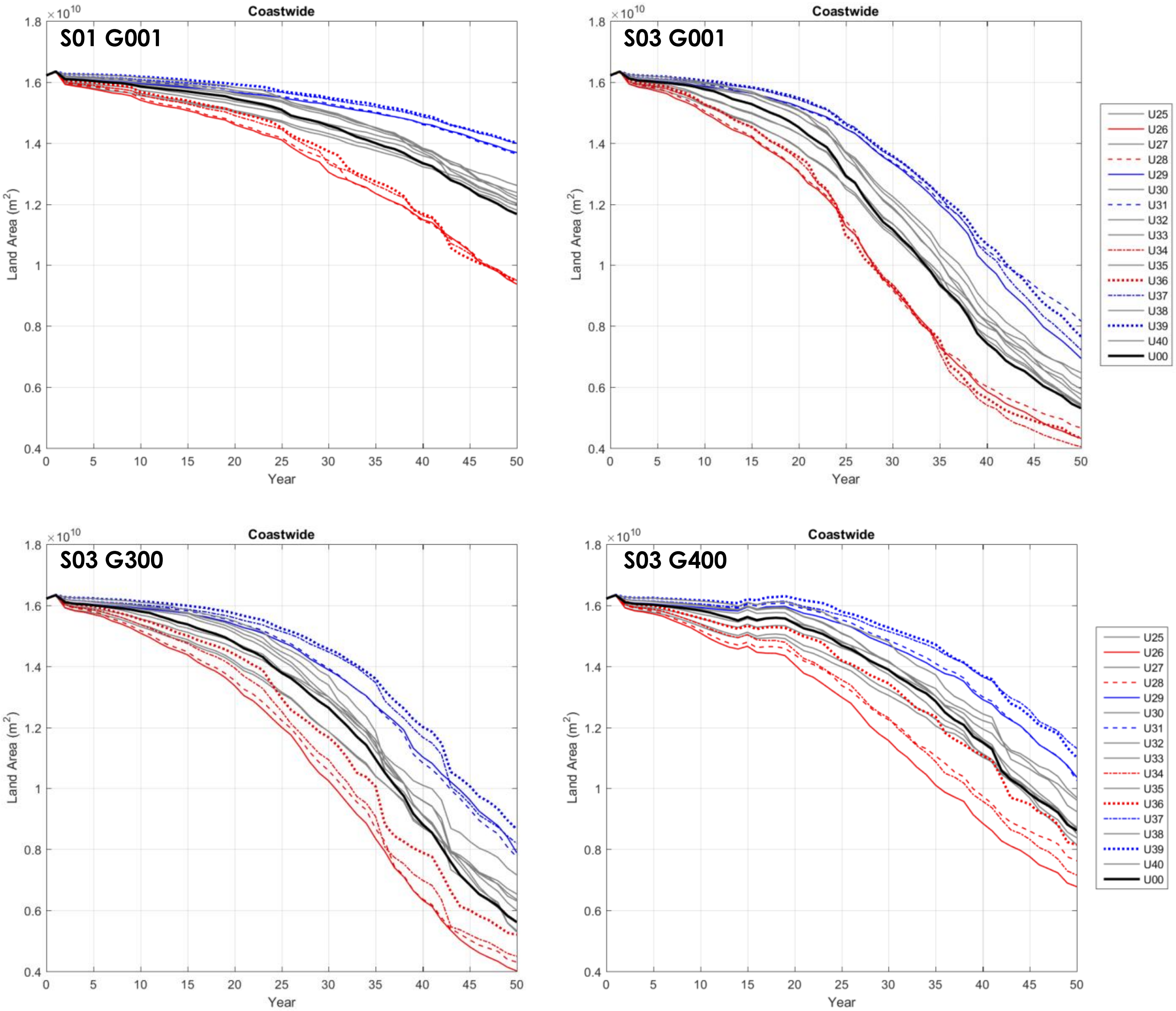

Figure 25: Land area change over time for total model domain area for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

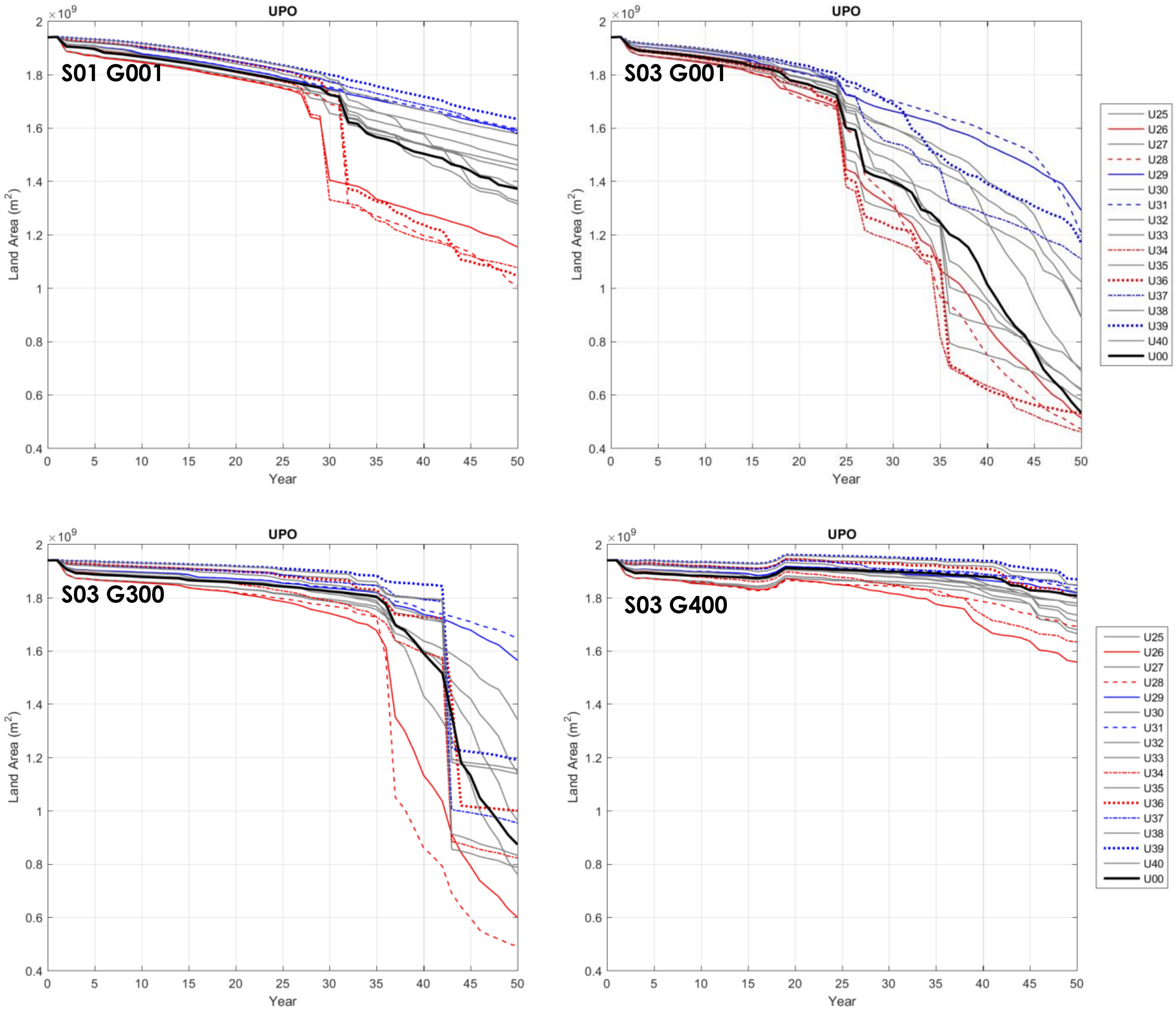

Figure 26: Land area change over time for Upper Pontchartrain (UPO) Ecoregion for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

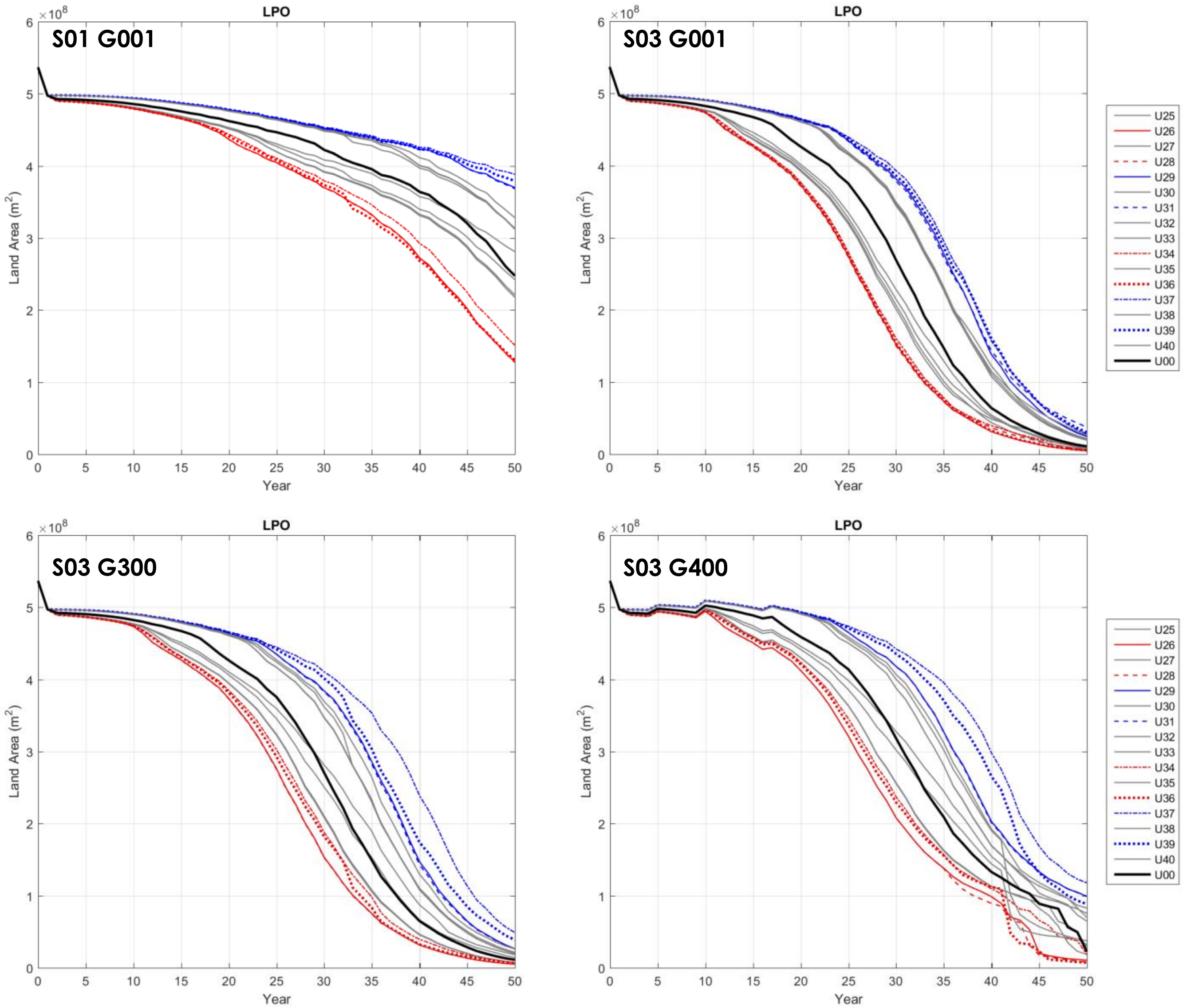

Figure 27: Land area change over time for Lower Pontchartrain (LPO) Ecoregion for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

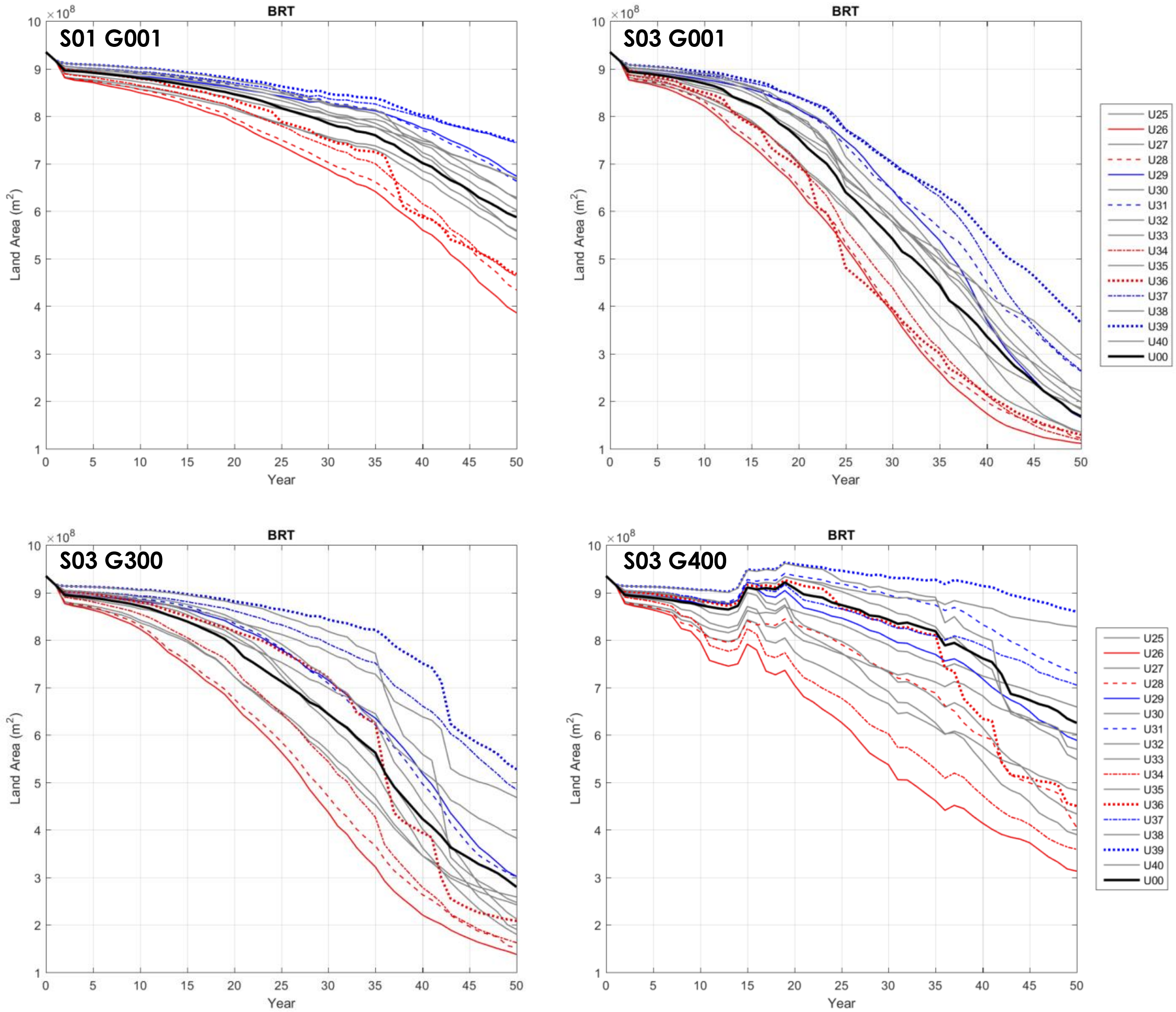

Figure 28: Land area change over time for Breton (BRT) Ecoregion for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

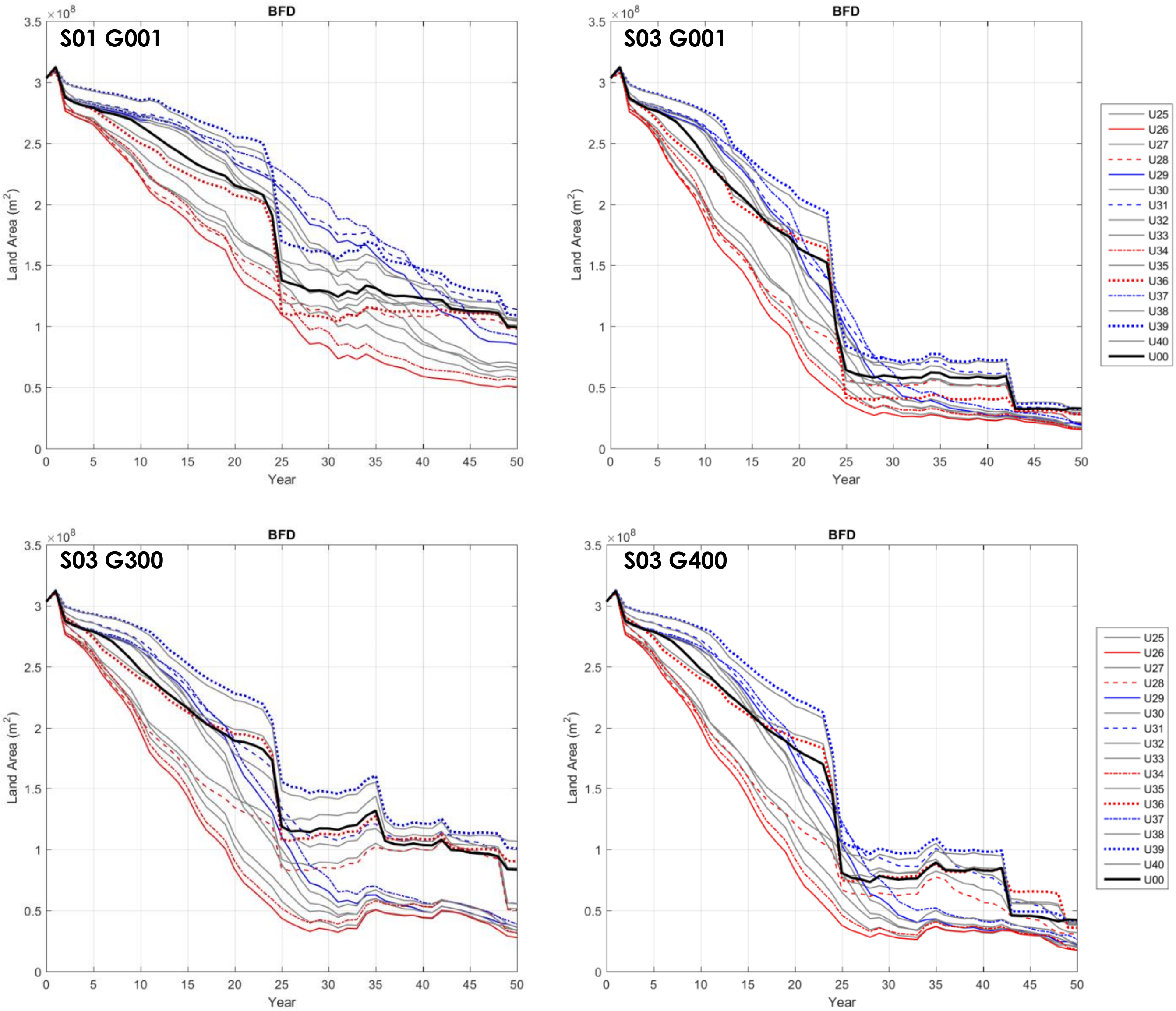

Figure 29: Land area change over time for Bird's Foot Delta (BFD) Ecoregion for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

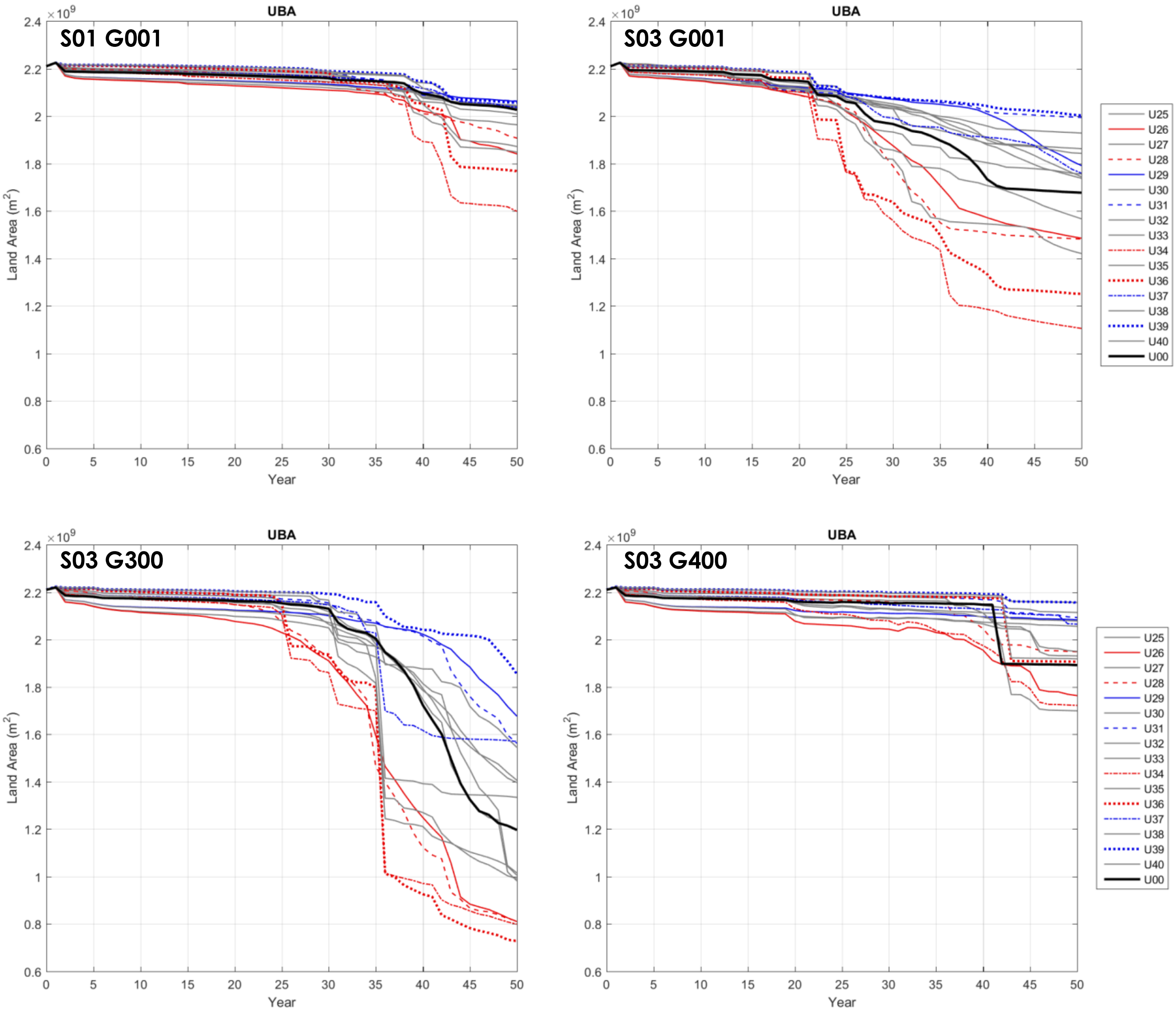

Figure 30: Land area change over time for Upper Barataria (UBA) Ecoregion for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

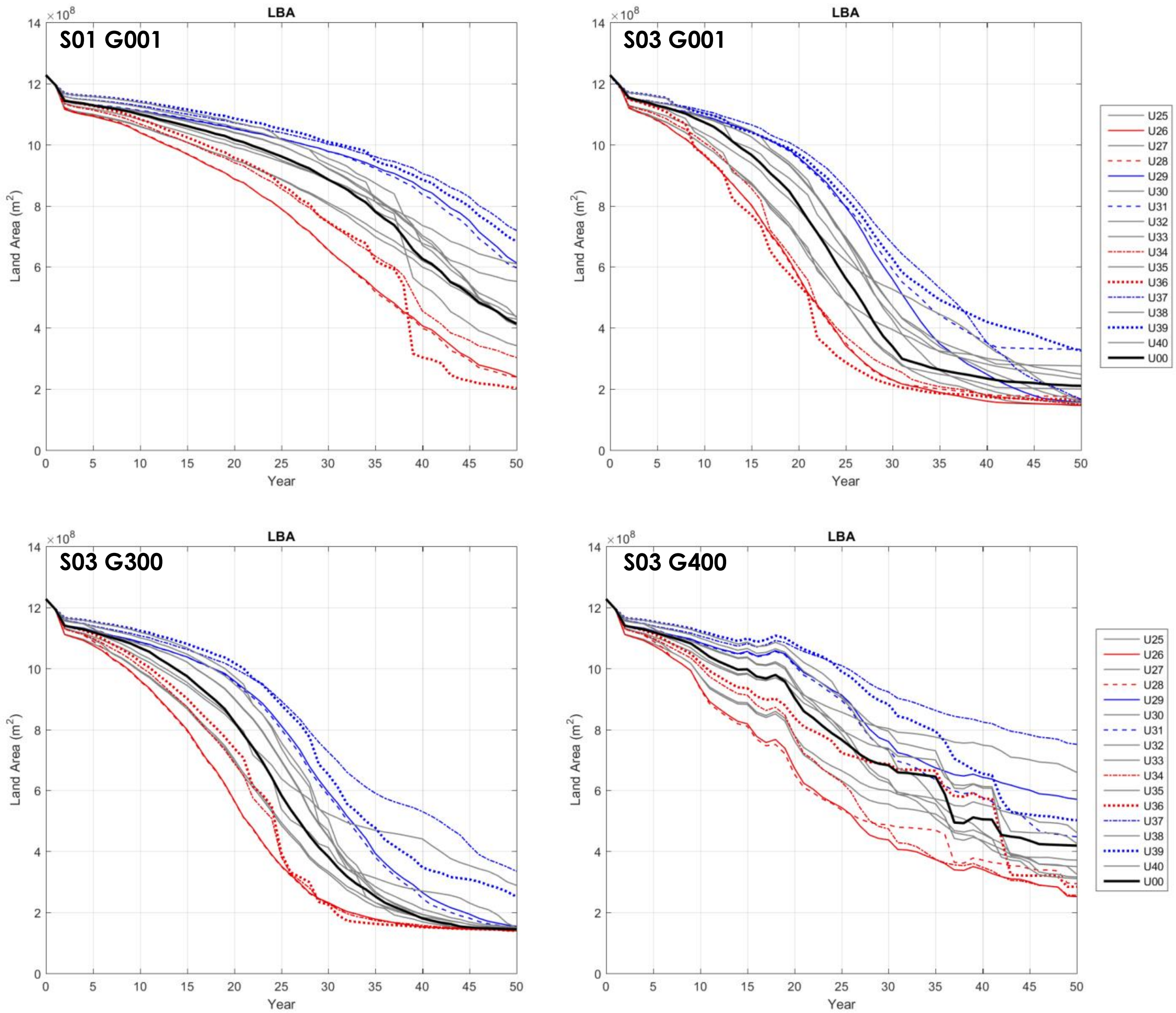

Figure 31: Land area change over time for Lower Barataria (LBA) Ecoregion for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

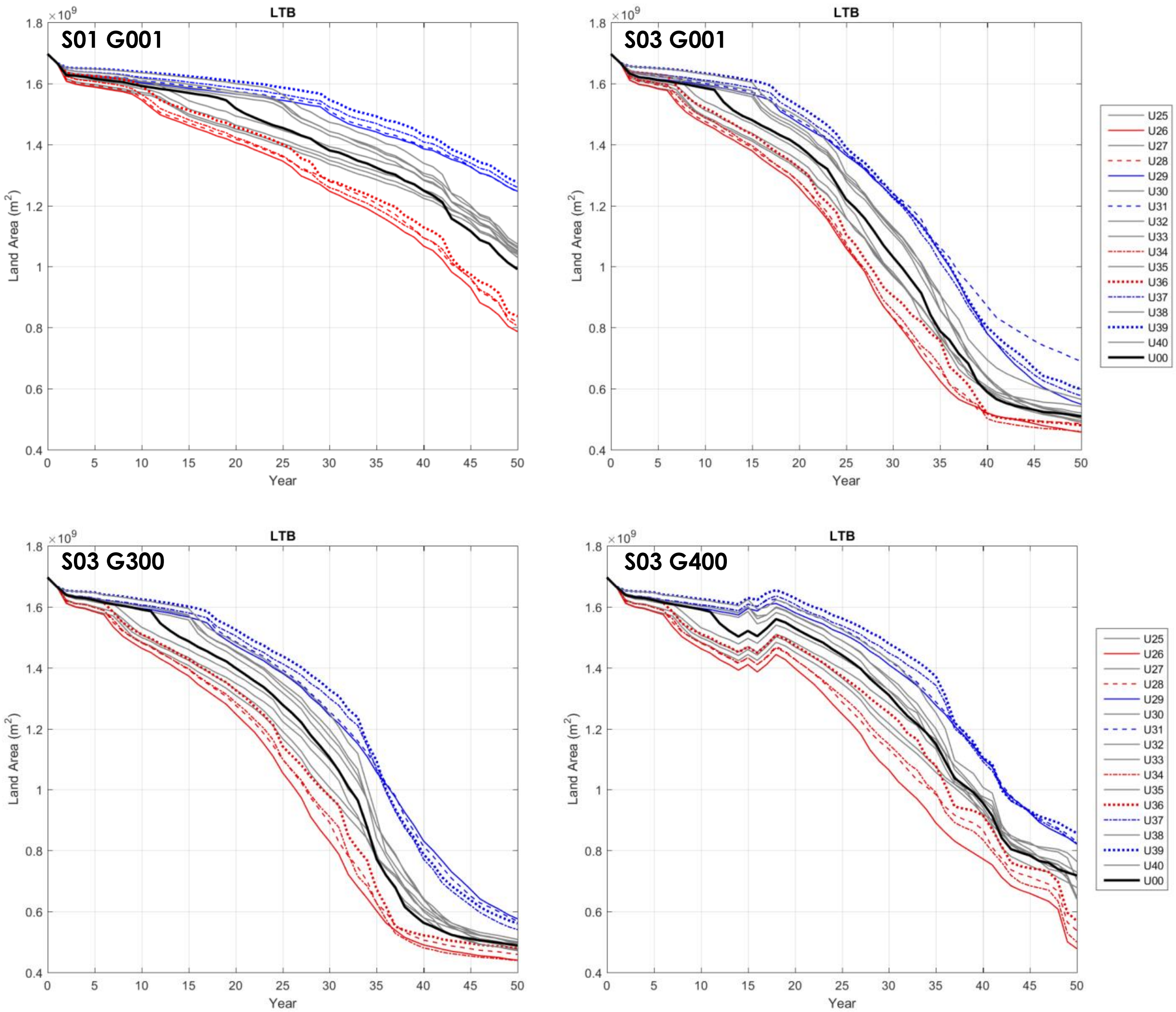

Figure 32: Land area change over time for Lower Terrebonne (LTB) Ecoregion for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

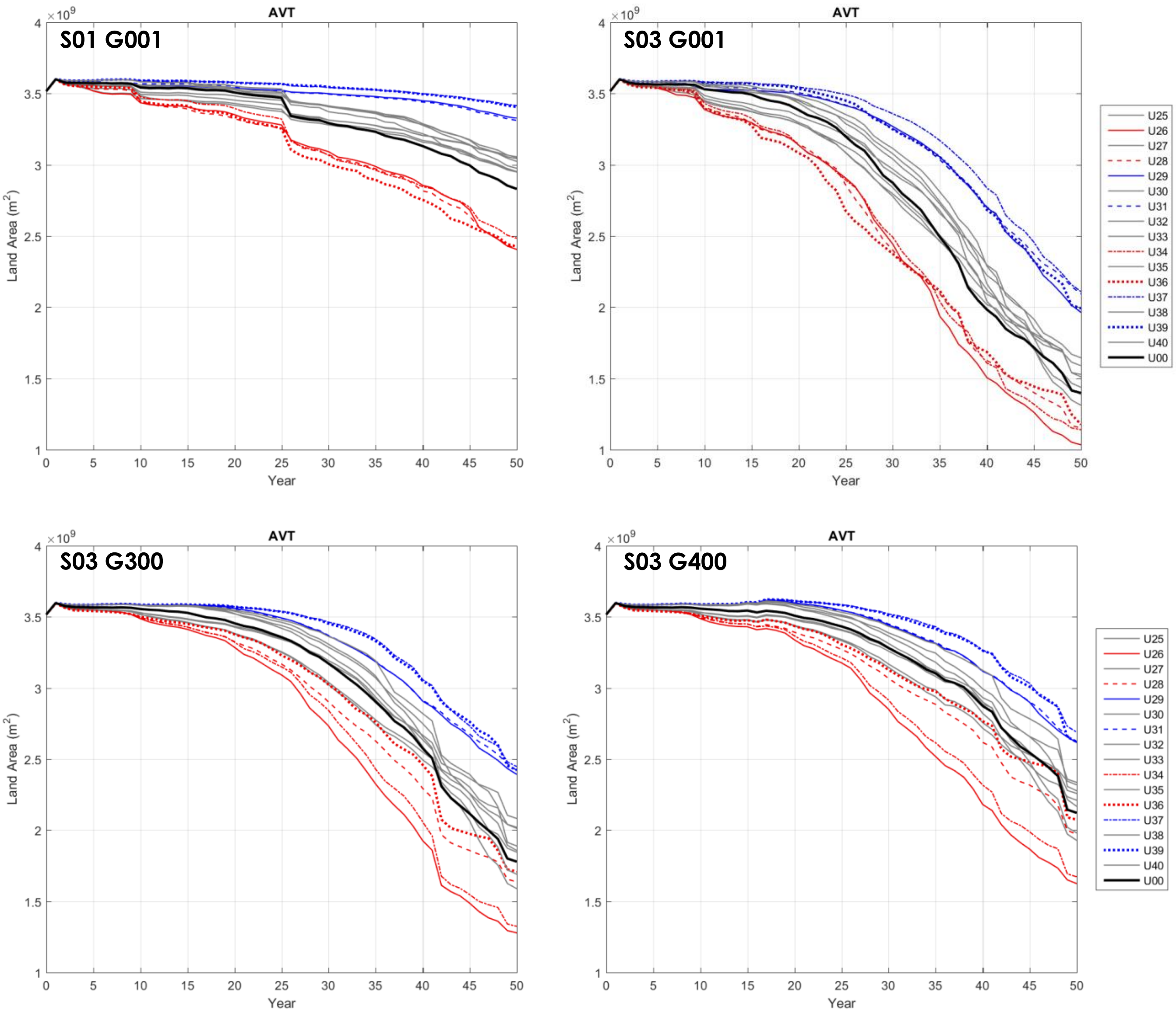

Figure 33: Land area change over time for Atchafalaya/Teche/Vermilion (AVT) Ecoregion for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

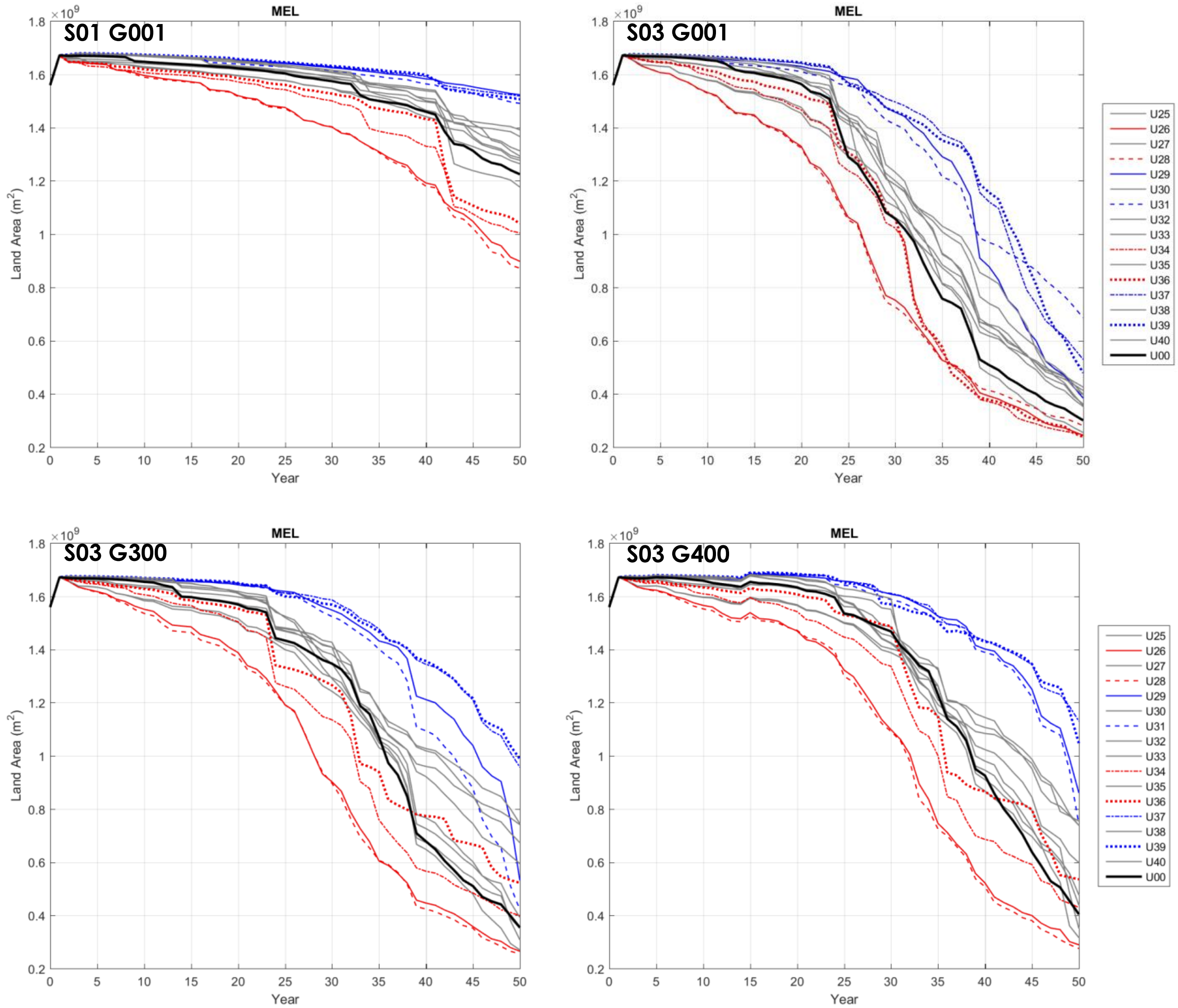

Figure 34: Land area change over time for Mermentau/Lakes (MEL) Ecoregion for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

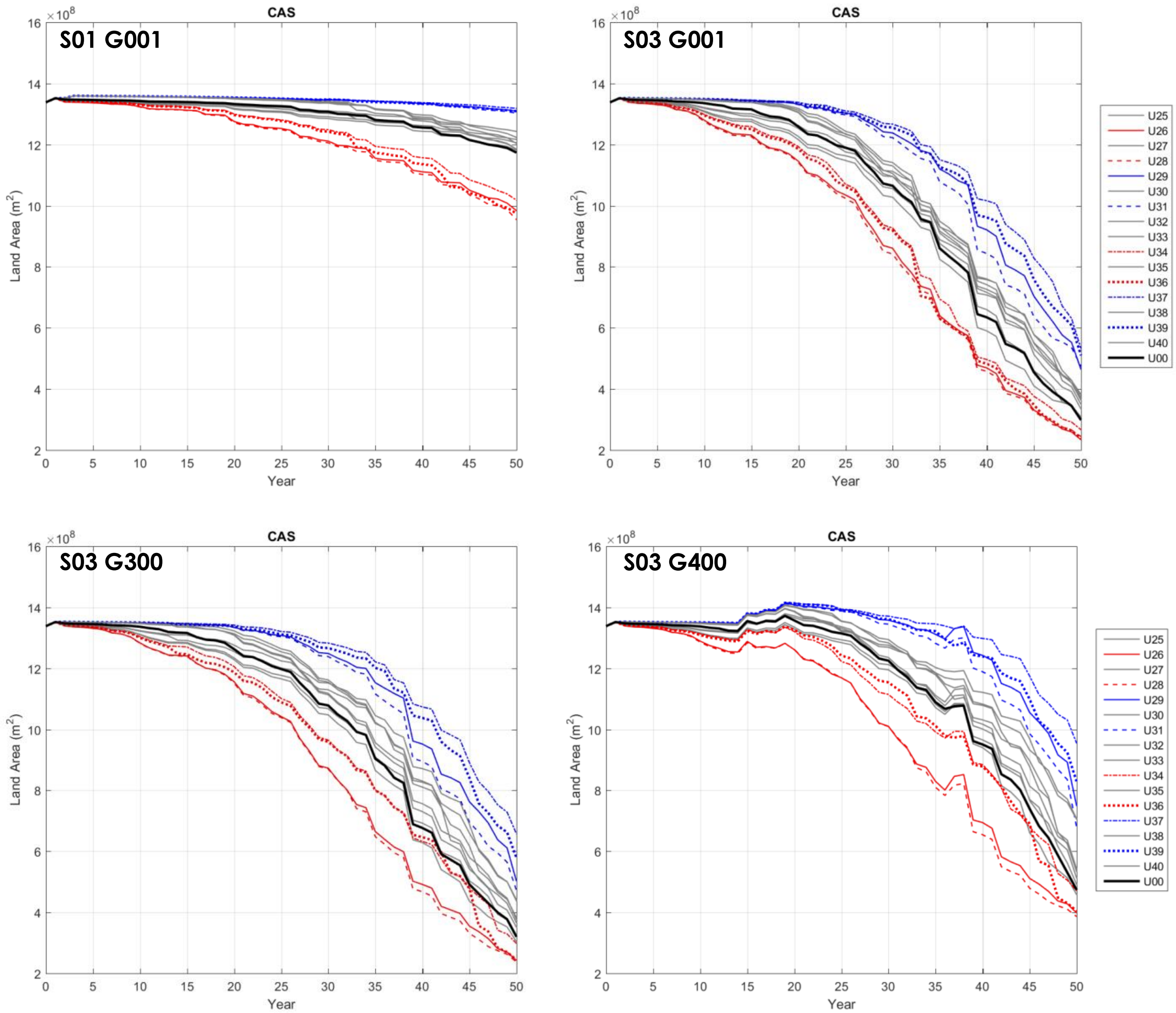

Figure 35: Land area change over time for Calcasieu/Sabine (CAS) Ecoregion area for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

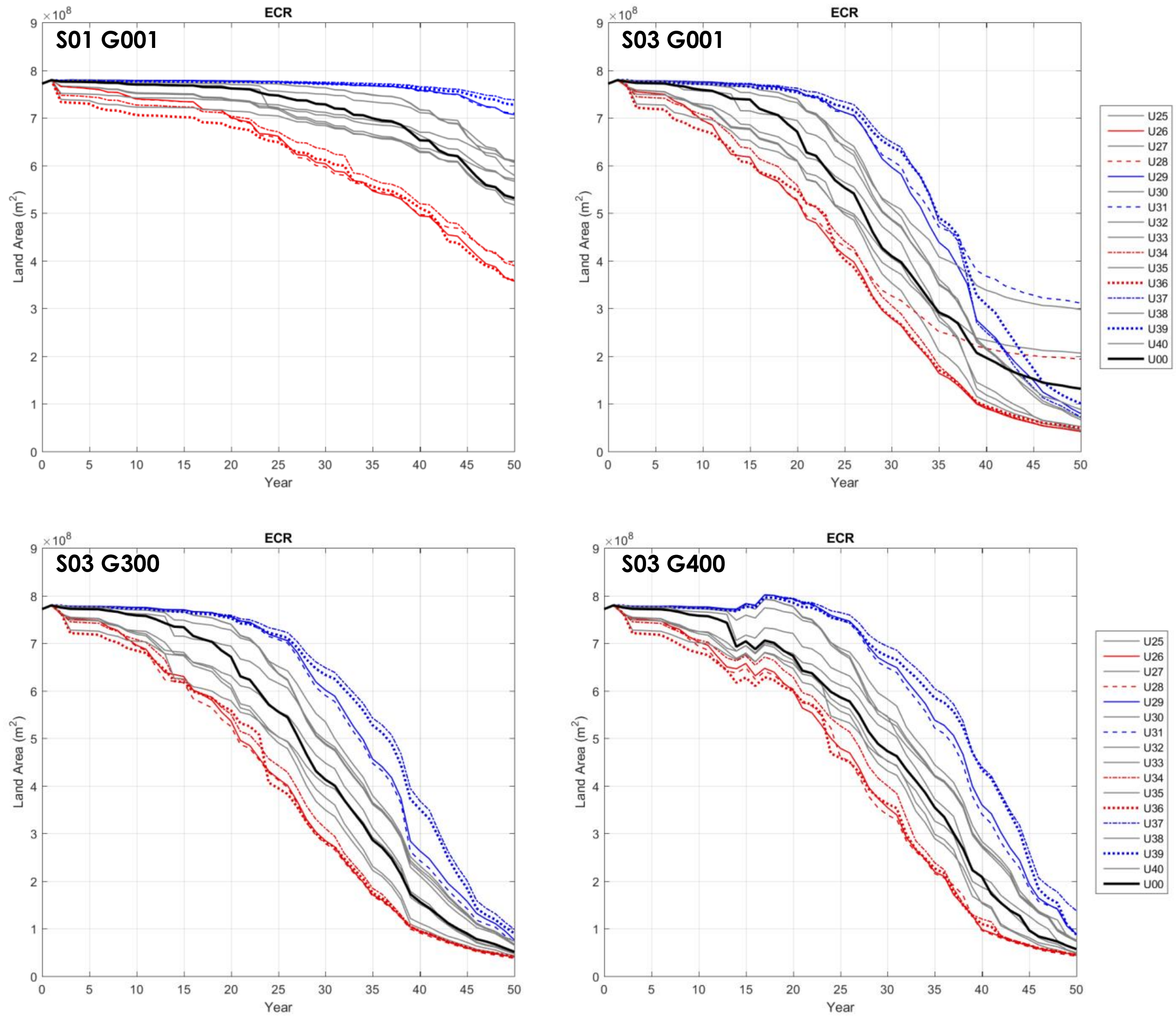

Figure 36: Land area change over time for Eastern Chenier Ridge (ECR) Ecoregion for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

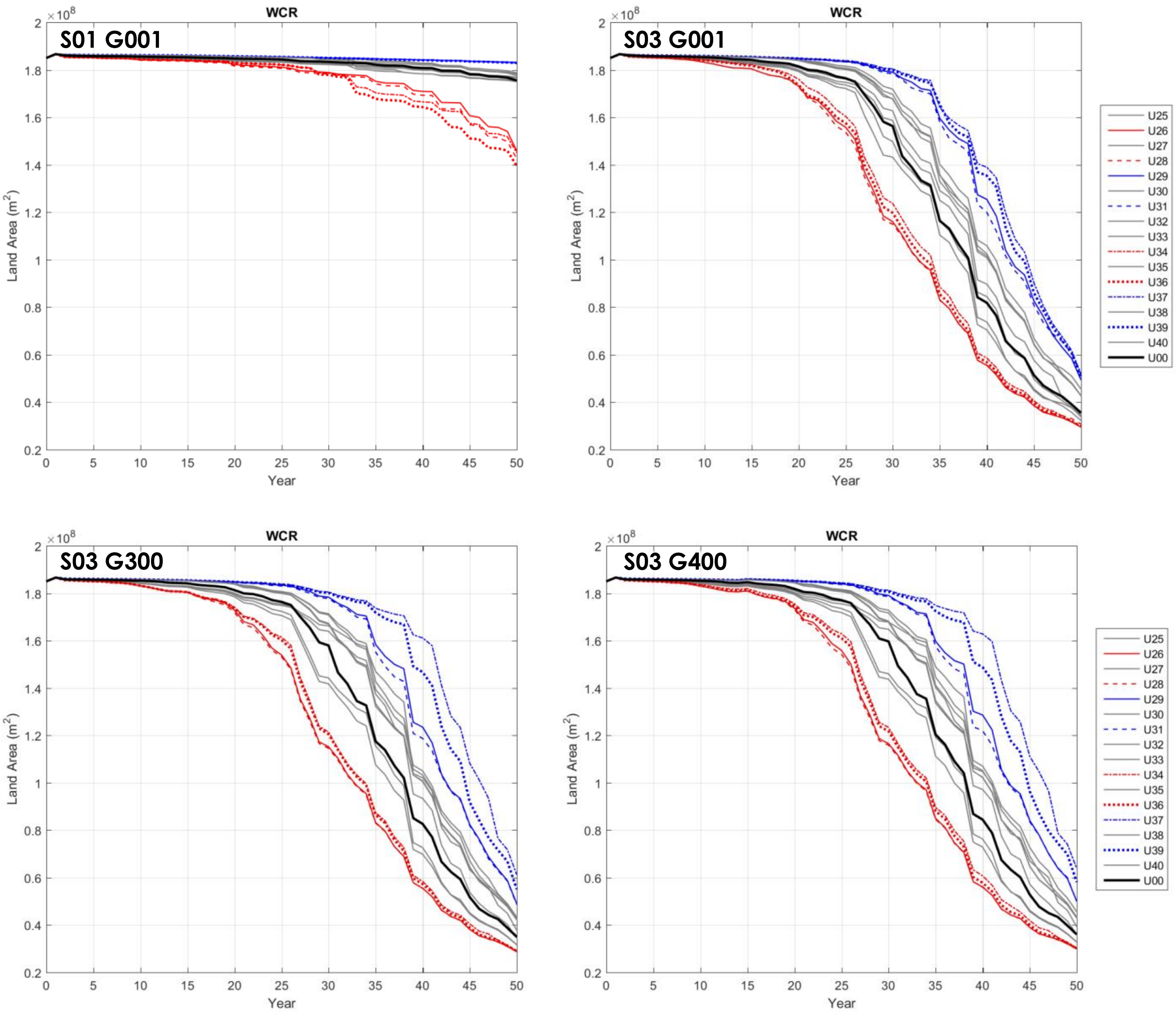

Figure 37: Land area change over time for Western Chenier Ridge (WCR) Ecoregion for four analyses: low scenario FWOA_v1 (S01 G001), high scenario FWOA_v1 (S03 G001), high scenario FWOA_v3 (S03 G300), and high scenario Draft Master Plan (S03 G400). Blue lines indicate permutations where mean water level was reduced and organic accretion was increased. Red lines indicate permutations where mean water level was increased and organic accretion was decreased. The black line is the baseline case (U00).

8.0 Additional Model Sensitivity Analysis

In addition to the parameters analyzed throughout the uncertainty analysis and discussed in this report, several additional model parameters were identified by the 2017 Coastal Master Plan modeling team as warranting further investigation regarding the sensitivity of their impact on ICM predicted land area. Of particular interest are two variables not included in the uncertainty analysis described thus far in this report: subsidence rates and marsh collapse thresholds. Additionally, due to the relative sensitivity of land area predictions to organic accretion rates, model output from the individual perturbation runs described in Section 4.4 were further analyzed for spatial patterns when testing across the entire range of organic accretion rates included in these analyses.

8.1 Model Sensitivity to Organic Accretion Input Data

Unlike other perturbed variables included in the uncertainty analysis, the organic component of vertical accretion within the marsh was not able to be perturbed based on model performance statistics. Therefore, the input data to the model was adjusted by the variance inherent to the observed organic matter and bulk density data that were used to build the model input files (see Section 3.3). To assess model sensitivity to these terms, the year 50 land/water output was examined from the two cases in which the extremes of the organic accretion data were used: U11 and U12. The total extent of land/water area sensitive to the range in organic accretion inputs is shown in Figure 38. If a land/water pixel is gray in this image, it is land regardless of whether or not the organic accretion input data is at a minimum or maximum value. Conversely, the pixel is white if it is water regardless of input organic accretion data. The pixels that are green would be land when the maximum organic accretion values are used as input and would be water when the minimum values are used. Pixels that are red would be predicted to be land when the low organic accretion values are used and water when the high organic accretion values were assigned. Sensitivity to organic accretion is only due to the individual variable perturbation; interactions between parameters from composite variable perturbations (tested under the 16 described uncertainty permutations) were not examined.

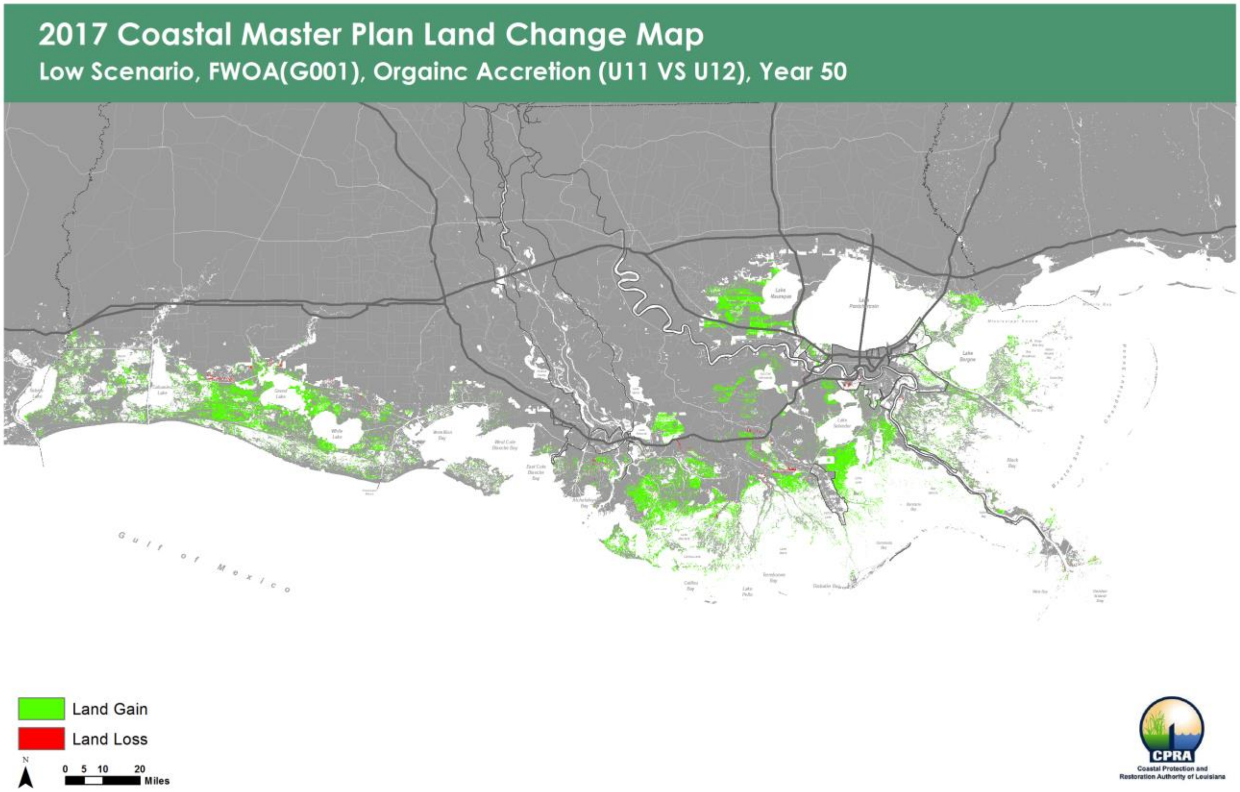

Figure 38: All land under low scenario FWOA using ICM_v1 that is sensitive to individual perturbation of organic accretion inputs. Any land/water pixel that is green was water at year 50 when the low value of organic accretion is used (U12) and was land at year 50 when the high value of organic accretion was used (U11). Red represents pixels predicted to be land when the low value of organic accretion was used and land when the high organic accretion values were used.

8.2 Model Sensitivity to Subsidence Rates

As part of the development of the environmental scenarios used for the 2017 Coastal Master Plan, numerous subsidence rates were tested in the ICM. A full discussion of these analyses is provided in Appendix C: Modeling, Chapter 2: Future Scenarios. Of the five candidate scenarios developed under that analysis, three of the scenarios all utilized the same eustatic sea level rise rate (0.63 m over 50 years). These three scenarios (S02, S04, and S05) were all identical with the exception of the subsidence rates used; three different subsidence rates were tested: 20%, 35% and 50% into the range of subsidence observations. A subsidence rate of “20% into the range” indicates that the subsidence rate was set to a value that was 20% between the minimum and maximum observed rate for a given subsidence zone. For example if the observed data ranged from 5 mm/yr to10 mm/yr, 20% into the range would be a rate of 6 mm/yr, 35% would be 6.75 mm/yr, and 50% into the range would be a rate of 7.5 mm/yr. Since everything except subsidence rate was held constant for these three runs, the spatial patterns of model sensitivity to subsidence rates can be shown.

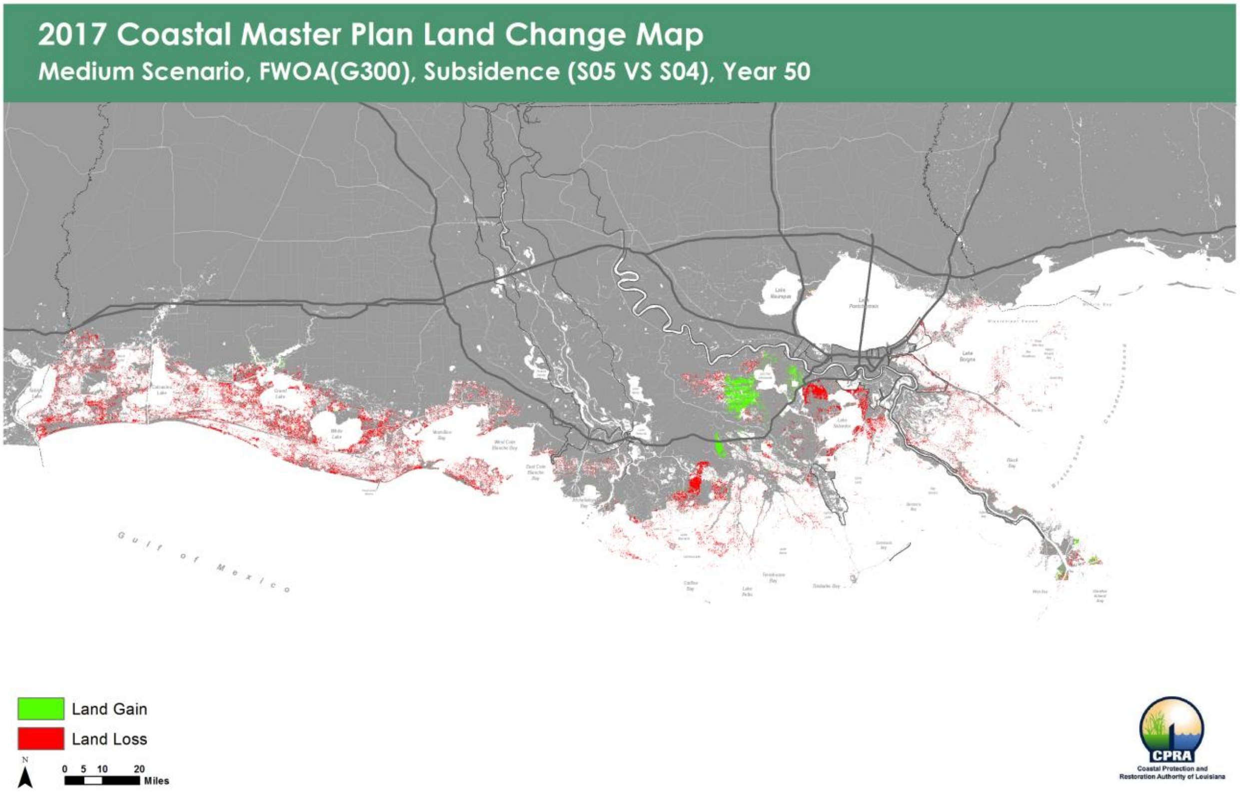

Figure 39: Sensitivity range in land predicted at year 50 under the low subsidence rate (S04: 20%) and the medium subsidence rate (S05: 35%). Any land/water pixel that is red was water at year 50 when the medium subsidence rate was used and was land at year 50 when the low subsidence rate was used. Green represents pixels that are predicted as land when the medium subsidence rate was used and water when the low subsidence rate was used.

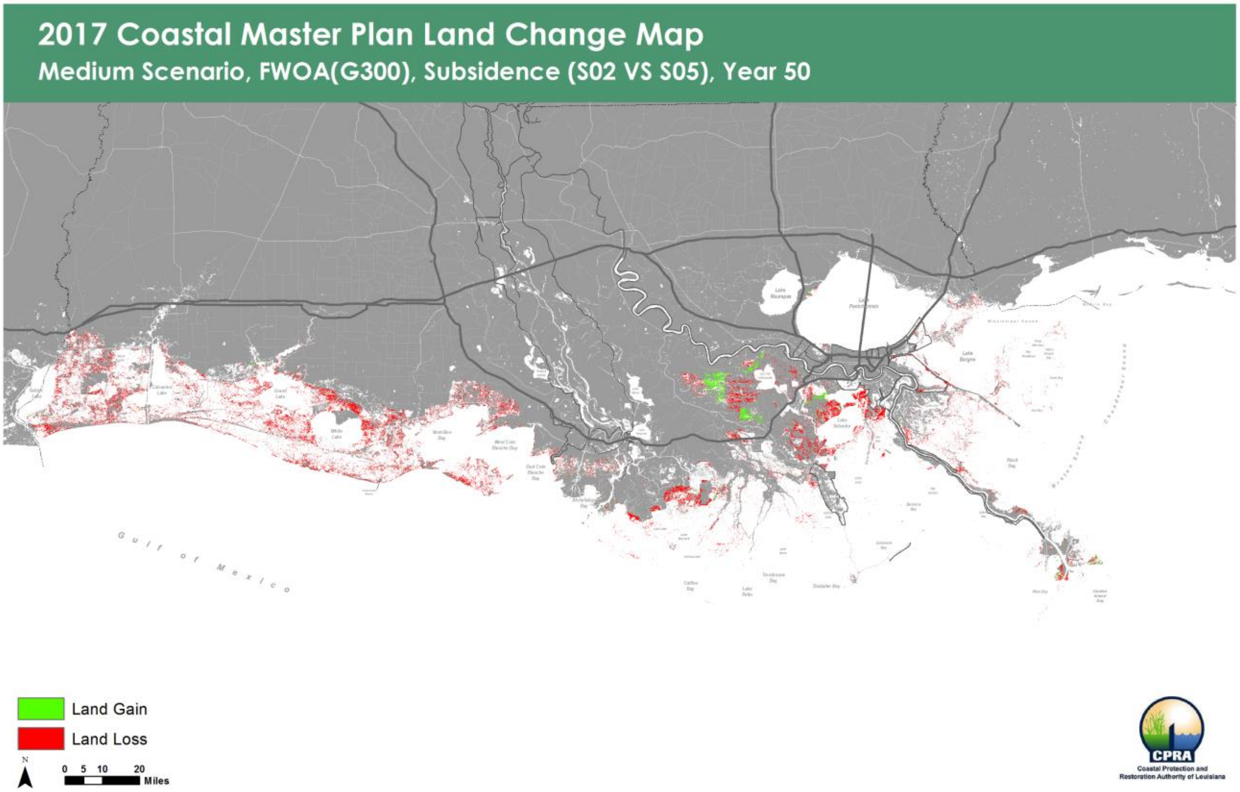

Figure 40: Sensitivity range in land predicted at year 50 under the medium subsidence rate (S05: 35%) and the high subsidence rate (S02: 50%). Any land/water pixel that is red was water at year 50 when the high subsidence rate was used and was land at year 50 when the medium subsidence rate was used. Green represents pixels that are predicted as land when the high subsidence rate was used and water when the medium subsidence rate was used.

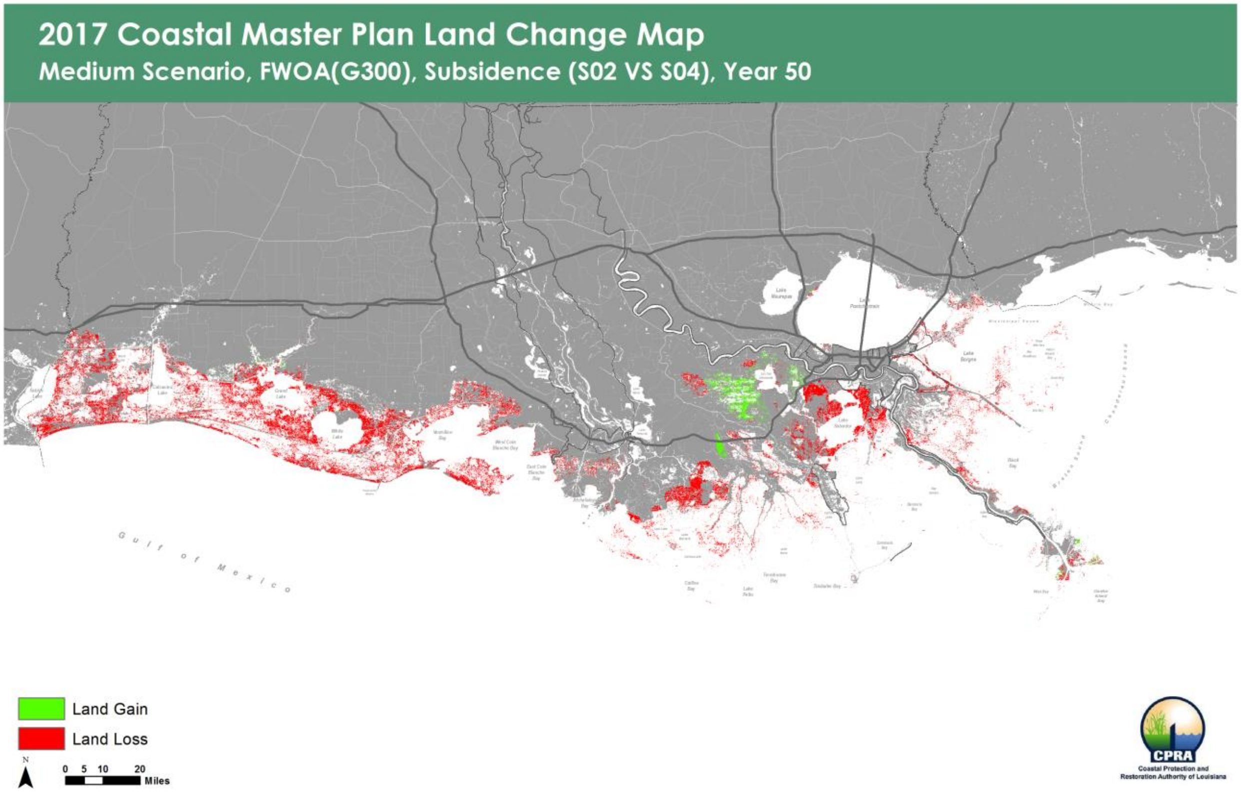

Figure 41: Sensitivity range in land predicted at year 50 under the low subsidence rate (S04: 20%) and the high subsidence rate (S02: 50%). Any land/water pixel that is red was water at year 50 when the high subsidence rate was used and was land at year 50 when the low subsidence rate was used. Green represents pixels that are predicted as land when the high subsidence rate was used and water when the low subsidence rate was used.

With respect to model uncertainties tested and discussed in this report, it appears that the model sensitivity to subsidence rates tested and used for the master plan modeling are of the same magnitude (or greater) than the uncertainties in model output introduced by the perturbations defined by model performance statistics.

8.3 Model Sensitivity to Marsh Collapse Thresholds

The marsh collapse thresholds used in the 2017 Coastal Master Plan analyses were chosen based on the coast wide mean inundation that coincides with vegetated biomass that is two standard deviations below the mean biomass (as represented by the normalized vegetation index) (Couvillion & Beck, 2013). The 2012 Coastal Master Plan Marsh Collapse Threshold Advisory Panel analyzed this same data and provided inundation values for each coastal basin, which were more variable than the coast wide averages ultimately used (in both 2012 and 2017) (CPRA, 2011). To assess model sensitivity, the extreme values for each marsh type from all coastal basins were used as the inundation collapse thresholds (Table 5). Additionally, sensitivity of fresh marsh to salinity collapse was assessed by adjusting the length of time used to define the maximum salinity. The model sensitivity was tested with the following seven conditions:

1. Adjust intermediate marsh threshold down (use High Collapse Inundation Threshold)
2. Adjust intermediate marsh threshold up (use Low Collapse Inundation Threshold)

3. Adjust brackish marsh threshold down (use High Collapse Inundation Threshold)
4. Adjust brackish marsh threshold up (use Low Collapse Inundation Threshold)
5. Adjust salt marsh threshold down (use High Collapse Inundation Threshold)
6. Adjust salt marsh threshold up (use Low Collapse Inundation Threshold)
7. Adjust fresh marsh collapse to use growing season salinity (consistent with 2012 models) rather than two-week mean salinity

Table 5: Inundation collapse thresholds used to assess model sensitivity. Original analysis summarized in Table 2 of the 2012 Marsh Collapse Threshold Advisory Panel Summary Report. Collapse thresholds are the depth of inundation (meters) over the marsh surface in which the marsh will still survive. Persistent inundation deeper than this threshold depth will result in wetland collapse.

	Original Inundation Threshold Value Used in 2017 Coastal Master Plan	**Low Collapse Inundation Threshold from 2012 Marsh Collapse Threshold Panel Report**	**High Collapse Inundation Threshold from 2012 Marsh Collapse Threshold Panel Report**
Intermediate	0.358 m	0.443 m	0.140 m
Brackish	0.256 m	0.386 m	0.190 m
Saline	0.235 m	0.399 m	0.135 m

As evident in the following figures, the model sensitivity to the range in collapse thresholds is spatially variable as a result of the predominant vegetation in a given area. Due to the fact that saline marsh is the predominant vegetation type in later decades, it is intuitive that the range in predicted land area at year 50 is most sensitive across the range of saline marsh collapse thresholds (Figure 42).

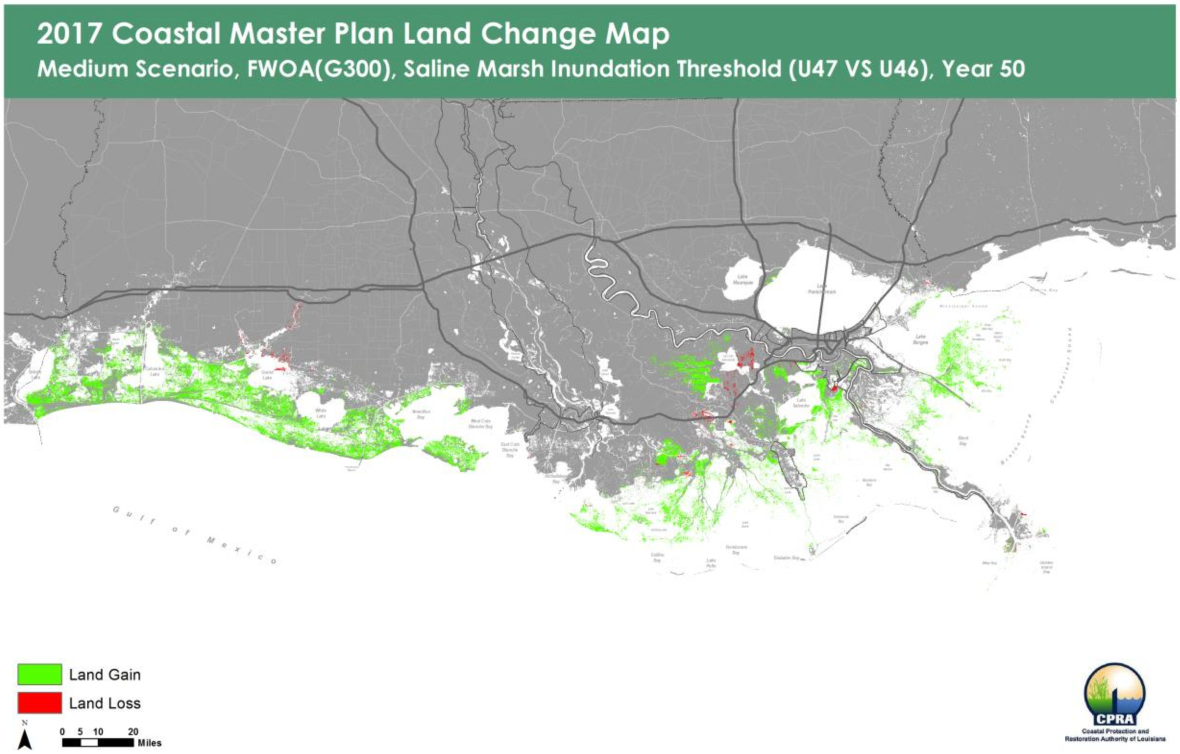

Figure 42: Sensitivity range in land predicted at year 50 under the extreme saline marsh collapse threshold values. Pixels that are green are predicted as land when saline marshes are more inundation tolerant and predicted as water when saline marshes are less tolerant to inundation. Red represents pixels that are predicted as water when saline marshes are more inundation tolerant and predicted as land when saline marshes are less inundation tolerant.

Brackish marsh is the second most prevalent type of vegetation at year 50, and the model sensitivity to the brackish marsh inundation threshold is similarly less than the sensitivity to the saline marsh inundation threshold range (Figure 43). Following this same trend, intermediate marsh is even less prevalent at year 50 in the model and therefore the model is least sensitive to the intermediate marsh inundation threshold (Figure 44).

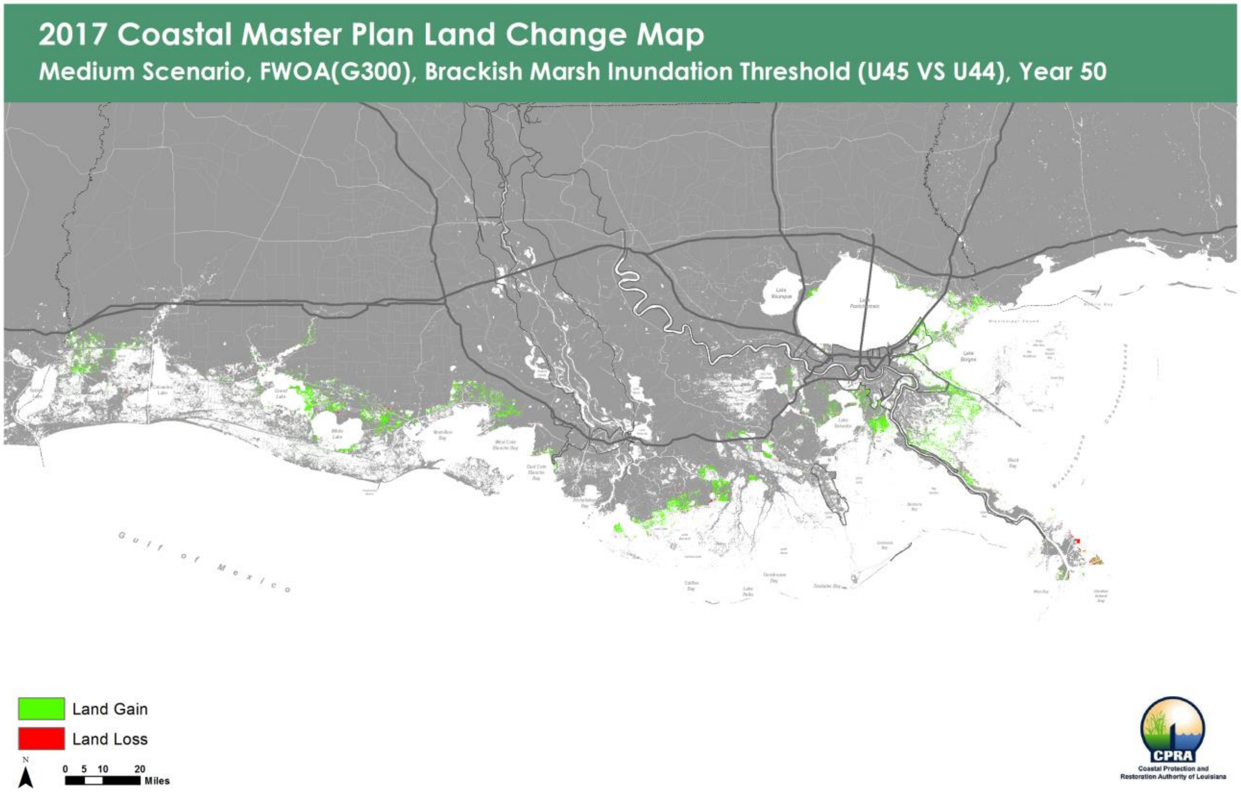

Figure 43: Sensitivity range in land predicted at year 50 under the extreme brackish marsh collapse threshold values. Pixels that are green are predicted as land when brackish marshes are more inundation tolerant and predicted as water when brackish marshes are less tolerant to inundation. Red represents pixels that are predicted as water when brackish marshes are more inundation tolerant and predicted as land when brackish marshes are less inundation tolerant.

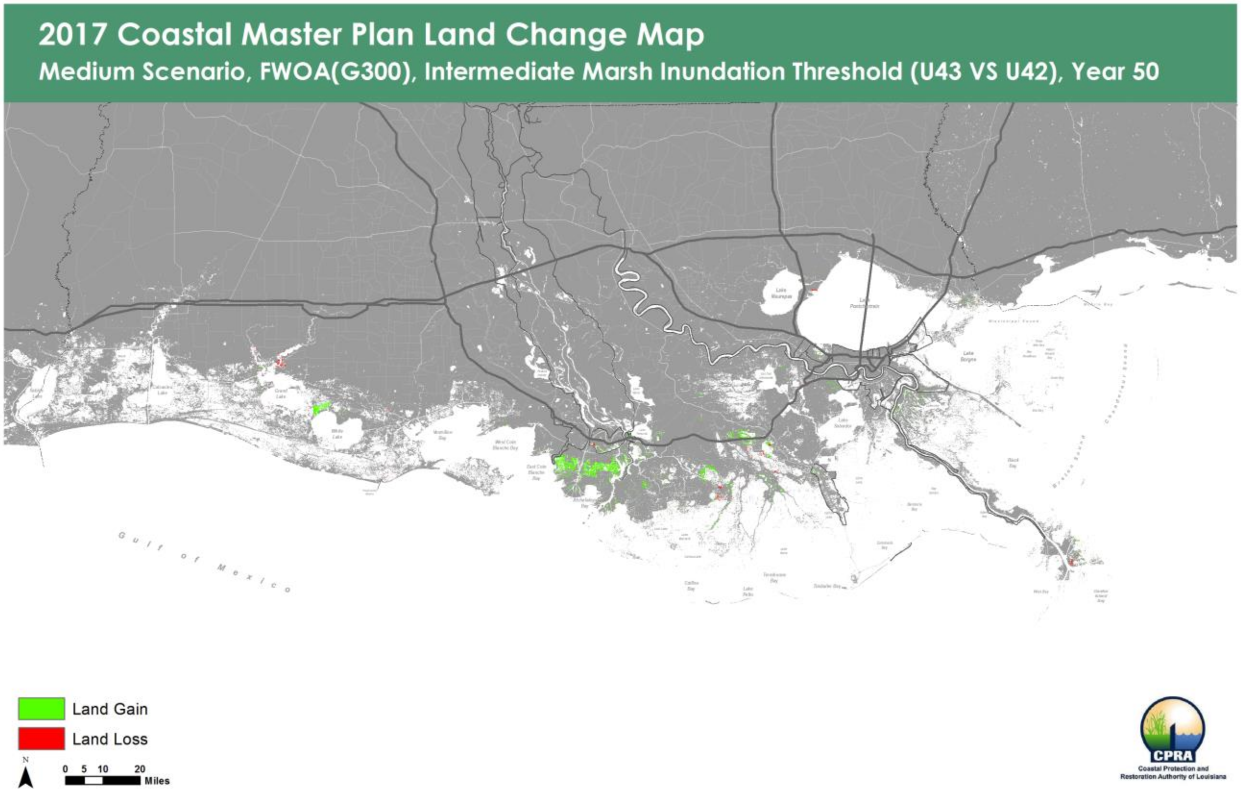

Figure 44: Sensitivity range in land predicted at year 50 under the extreme intermediate marsh collapse threshold values. Pixels that are green are predicted as land when intermediate marshes are more inundation tolerant and predicted as water when intermediate marshes are less tolerant to inundation. Red represents pixels that are predicted as water when intermediate marshes are more inundation tolerant and predicted as land when intermediate marshes are less inundation tolerant.

The final marsh collapse variable tested in this sensitivity analysis was the salinity value used to define the collapse-inducing salinity in fresh wetland regions. For the 2017 Coastal Master Plan, the maximum two-week mean salinity of the year is used to define the salinity value in which fresh wetlands may experience salinity stress. This was updated from the 2012 Coastal Master Plan, which used the annual mean salinity to define the collapse-inducing salinity. Therefore, by comparing land area from these two approaches, it can be shown as to what portion of the model domain is subjected to very short periods of salinity stress that result in land loss. By year 50, this is mostly evident in the upper regions of Terrebonne and Barataria (Figure 45), which are both prone to periodic salinity spikes in later simulation years due to higher sea level and periodic droughts during summer months.

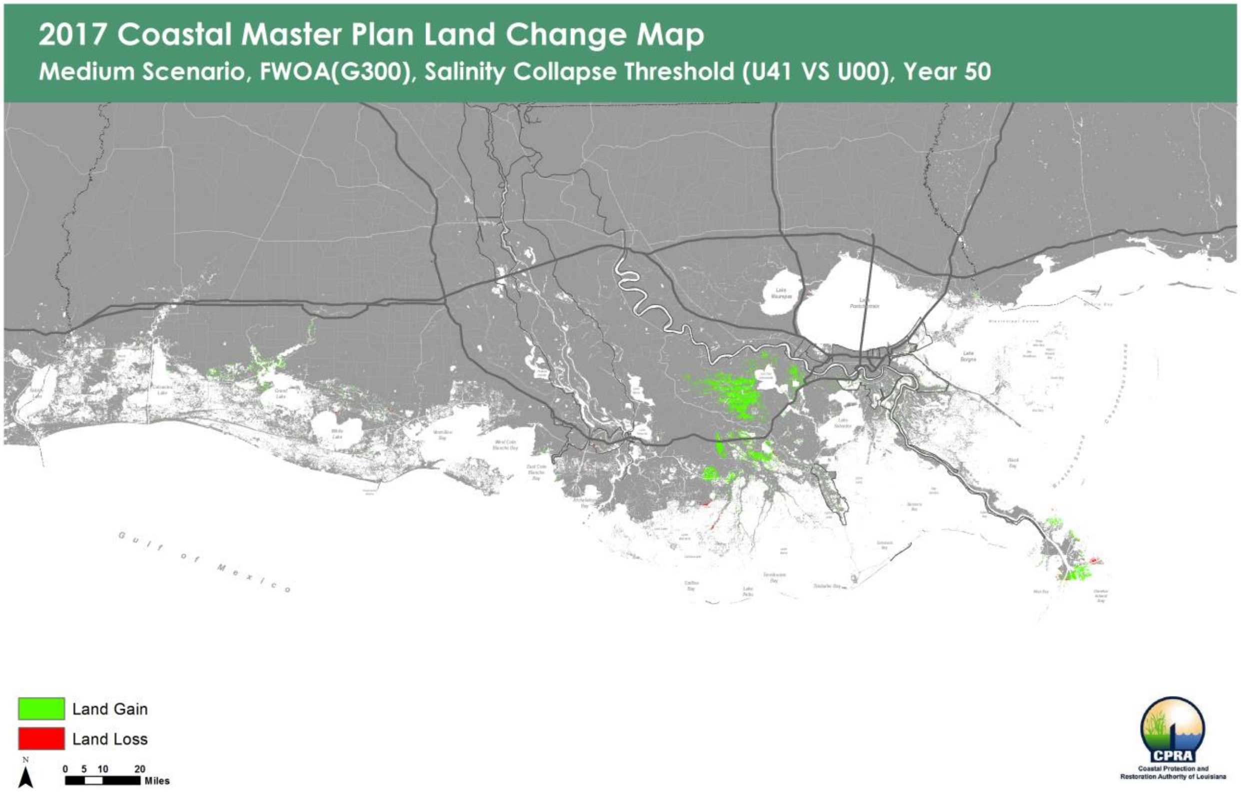

Figure 45: Sensitivity range in land predicted at year 50 under the different fresh marsh salinity stress collapse routines. Pixels that are green are predicted as land when the annual mean salinity is used to define the stress-inducing salinity and predicted as water when the maximum two-week mean salinity of the year was used.

As shown in these sensitivity analysis simulations, the final extent of land area predicted by the ICM is fairly sensitive to the marsh collapse threshold values chosen for a given simulation. The analysis conducted for the 2012 Coastal Master Plan produced spatially variable representations of marsh inundation that could be operationalized in future simulations for a more complex representation of marsh collapse; however, regardless of spatially variability in collapse threshold values, the utilization of a collapse threshold methodology still represents an inherently dynamic and complex process with a relatively simple Boolean operator. Incorporation of the marsh collapse thresholds into the relative sea level rise scenarios approach (as was essentially done in the 2012 effort), may be an appropriate path forward if a more dynamic wetland collapse process is unable to be operationalized in future efforts.

9.0 Summary and Conclusions

This uncertainty analysis was based on applying perturbations to model variables that are directly linked to the calculations of land area. These model variables included water level, water level variability, salinity, TSS concentration, and organic accretion. The perturbations were applied to each of these variables before they were used in subsequent model subroutines. These perturbations were consistently applied through the 50-year simulations, and the magnitude of the perturbation of each variable was estimated based on the calibration errors. Perturbing wetland types were not examined here as they were controlled by the prevailing hydrologic conditions, and as such were removed from further consideration.

A set of experiments were designed to examine the perturbation of individual variables. The individual perturbations showed that water level and organic accretion have the most influence on land area. Salinity showed an influence on the wetland type but not on land area, while TSS showed minor influence on land area.

Additional composite experiments were performed to examine simple addition of uncertainties originating from individual perturbations. Further, and to fully examine the interdependency among the model variables, a set of 16 experiments was performed. These experiments provided a bracket of uncertainty around the FWOA baseline run. The results show that water level and organic accretion are the most influential on the coast wide land area.
Additional simulations were performed to examine the uncertainty in the calculations of land area under conditions identical to the scenarios used to formulate the 2017 Coastal Master Plan. The uncertainty in land prediction under a future with the Draft 2017 Coastal Master Plan implemented on the landscape was also assessed. Overall, the uncertainty in land area predicted increases over time under a low relative sea level rise scenario FWOA and decreases under a higher relative sea level rise scenario as any uncertainty from model error is overtaken by the extreme sea level rise rates. Once the Draft 2017 Coastal Master Plan is implemented, there is substantially more land throughout the model domain, as compared to FWOA. This increase in land area results in the Draft 2017 Coastal Master Plan permutations not converging upon the asymptotic lower limit as seen in the FWOA permutations. This subsequently leads to a larger uncertainty range than the FWOA permutations. Overall, and as seen in Figure 25, under all conditions, the Draft 2017 Coastal Master Plan results in more land area than the FWOA.

Many model input parameters were not able to be perturbed by the methodology followed for the uncertainty analysis, in which model performance errors were used to assign a perturbation factor to model outputs. The modeling team determined that the ICM prediction of land area at year 50 seemed to be particularly sensitive to three such parameters: subsidence rates, organic matter accretion, and marsh collapse threshold values. The spatial extent of model-predicted land area changed substantially due to setting these variables at extreme values. Of the marsh collapse threshold values, the year 50 prediction of land area within the model domain was most sensitive to the saline marsh inundation-induced collapse threshold; a finding in agreement with the fact that the majority of land remaining at year 50 under the medium scenario is saline marsh. The extent of land impacted by the total range tested in subsidence rates and organic matter input rates were roughly the same magnitude as the saline marsh collapse threshold. The land area predicted at year 50 was not as sensitive to collapse thresholds for brackish, intermediate, or fresh marsh types.

10.0 References

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